GROHW

Final Report

Provincie Overijssel

29 March 2022

Partners

ASFALTNU, HAN, HanzeNet, MTSA Technopower, Rabobank, brandeniers Branding & Growth, Saxion Hogeschool, Van Dorp, VOS, Witteveen+Bos

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SUMMARY

Accelerating together
A collective of 10 local companies and institutions joined forces to accelerate the energy transition by working together in the GROHW project. The participating parties are pioneers in their own sectors and are sharing their knowledge and experience in this project. Together, we are building the energy transition with green hydrogen as its most important building block. GROHW stands for GReen Oxygen, Hydrogen and Waste Heat.

What did we do?
With this consortium, we designed the **most optimal system** for the entire hydrogen chain on a local scale: from production to utilisation. The central question we tried answering is: 'How can we use this green hydrogen system to prevent overloading of the grid, so that we can continue to produce sustainable energy locally and affordably in the short term? To answer this question, we looked at the utilisation of oxygen, heat, next to the utilisation of hydrogen. The municipality of Deventer aims to be energy-neutral by 2030. This is a challenging ambition because the electricity grid is (almost) overloaded. This calls for creative solutions, such as the green hydrogen system we envisage with GROHW. That's why GROHW also investigated if we could positively support the local grid. After the system design phase we developed an **elektrolyser** capable of our ambitions, **integrated the system** through setting up a basis of design and performed a (**socio-economical**) **business case analysis** of the complete system. Lastly, we developed a **digital trading platform** where energy flows can be controlled and settled intelligently.

Blueprint
At the moment, the city of Deventer is the pilot location, but this is only the beginning of GROHW. The ultimate goal is to create a blueprint that can be applied in similar areas around the world. This means we will try to draw lessons from the development of the Deventer project and evaluate & translate our findings into a standard methodology: the blueprint.

Conclusions
1 **Green Hydrogen**. Local green hydrogen over the entire value chain is of course the main focus of GROHW. We found which parameters effect the 'green' label and implemented this knowledge in our conceptual way of thinking. We also found which components influence other components and made decision trees to define high over system designs. Lastly, we gained insights in the possibilities and the limits of a local project.

2 **Societal impact**; we aim to have social impact by:
- The local and collaborative character; we make impact together. We share our knowledge and help each other. Our website and LinkedIn account inform interested about hydrogen, GROHW and lessons learned. We inform the public through the broad perspective of the different partners operating in the different industries. This is with the aim of creating broad social support. We have the ambition to digitalise the blueprint such that everyone can get inspired by this approach and is able to use it.
- The ambition to utilise the O (oxygen), the W (waste heat), and/or to supply flexibility services. Our systems are designed in such a way that utilisation of these two products can be switched 'on' or 'off', and we therefore produce less 'waste'. We now possess a value proposition for the successful local utilisation of oxygen produced in a full-scale system. We know what type of users are likely to utilise oxygen on a local scale and how this effects the business case. In our following project - the pilot project called GROHW-2, which is already running - we even experiment with the utilisation of waste heat. Sales of oxygen and/or waste heat have a very limited to no effect on the (socio-economical) business case. Preliminary research shows that flexibility services may have a positive effect on the SCBA, however, this must be explored in more detail.

3 **Blueprint approach**: we succeeded in developing a standardised approach for:
- The design of the system. We know how to move from an idea to a clear scope: we know which partners are essential for a project, how to use our decision trees to draft the initial project scope, how a by all partners supported system design looks like and how this design can be evaluated.

- The design of an electrolyzer and the components around it on a 1 - 5 MW scale. Our design is modularly built. We can choose between different configurations: with or without heat and oxygen, without additional compression, with or without large-scale storage, different hydrogen qualities and/or using different water qualities. Also, our communication strategy is modular.
- A Smart Energy Hub. We developed a blueprint of a digital platform in which the energy flows within a Smart Energy Hub are optimised in terms efficiency (MWh), business (Euros) and/or value case (minimal CO2 emissions)
- With the scalable/modular approach to marketing communications, we want to make it possible for parties who have newly joined the consortium, to quickly and easily be included in the branding and provide tools to tell the story from their own perspective without too much extra hassle.

Recommendations

1. Test the blueprint and the GROHW design in a Smart Energy Hub context and share knowledge. A first step is already taken with the start of our demonstration project (GROHW-2) at De Gasfabriek. To let interested people experience and learn about the possibilities of green hydrogen up close, GROHW-2 will host several demo days where people can view the demo set-up and gain knowledge.
2. We want to digitalise the blueprint, such that it can be used by everyone in an efficient way. To get here, we need to think of a digital strategy, and we need to add more detail to decision trees to achieve more precise results.
3. After the demonstration project we want to develop the hydrogen system further to a full-scale hydrogen system.
4. Investigate extending/optimising the lifespan of the stacks as the most critical component in the electrolyzer
5. Investigating the safest storage strategy for hydrogen, so that it is easier to incorporate in urban environments
6. Ensure that the results are reflected in the RELEASE project and, conversely, take the knowledge from RELEASE to strengthen a full scale and realisation phase with the lessons learned.
7. One to Zero: GROHW is a building block in a Smart Energy Hub concept. So: start working with the partners in Smart Energy Hub Deventer that the Deventer Economic Perspective is developing and accelerate the energy transition using OneToZero.

1

INTRODUCTION

1.1 Context of GROHW

A collective of 10 local companies and institutions are joining forces to accelerate the energy transition by collaborating on project GROHW. **GROHW** stands for **GR**een **O**xygen, **H**ydrogen and **W**aste heat. The participating parties are forerunners in their own sector and share their knowledge and experience in this project. 'Together we are building the energy transition with green hydrogen as the most important building block. '

Within this consortium we develop the most optimal system for the entire hydrogen value chain on a local scale: from production to utilization. The central question we are answering is 'How can we use green hydrogen production to prevent overloading of the grid, so that we remain sustainable in the short term on a local and affordable level? Beside hydrogen production, we also looking at the utilization of oxygen, heat and how we can positively support the local grid. In addition, we are developing a digital trading platform, where we cleverly manage and offset energy flows.

The local green hydrogen hub thus serves several purposes:
- Producing green hydrogen on a local scale
- Utilizing local renewable energy directly to alleviate grid overloading
- Utilizing the co-products of electrolysis: oxygen and heat
- The development of a digital trading platform

The outcome of GROHW is a scalable methodology that can be applied anywhere in the Netherlands or Europe at a local level: a valuable blueprint. By reflecting on the local case, we improve this blueprint through our lessons learned. This blueprint allows us and others to go through the design phase, implementation, and operation more quickly, with fewer costs and pitfalls.

This project has been made possible with a subsidy from the 'Kansen in Overijssel' programme of the Province of Overijssel. At this moment we started a second GROHW project called GROHW-2 which is a demonstration of the entire hydrogen system at the Gasfabriek in Deventer. We aim to realise a full-scale hydrogen system named GROHW-3 and are currently gathering partners for this project.

1.2 Reading guide

This report comprises five chapters:
- Chapter 1 Introduction of GROHW
- Chapter 2 branding of GROHW - One to Zero
- Chapter 3 blueprint methodology
- Chapter 4 the Deventer case
- Chapter 5 contains the conclusions and recommendations
- Finally, there are several appendices to elaborate on subjects in more detail. References to these appendices are made in the report itself

The city of Deventer is currently the pilot location, but this is only the beginning of GROHW. The ultimate goal is to create a blueprint that can be used in similar areas around the world. This means that we will try to learn the lessons in the pilot location and evaluate and translate our findings into a standard methodology: the blueprint. These two levels are considered in two separate chapters:

- The blueprint methodology
- The Deventer case

These chapters are split in seven paragraphs:

1 Developing the project
2 Scoping the project
3 Designing the system
4 Electrolyser design
5 System integration
6 Trading platform
7 Business case and financeability analysis

2

BRANDING OF GROHW - ONE TO ZERO

2.1 Communication philosophy

The idea behind the communication philosophy of GROHW - OneToZero is that we are building a central platform with a fixed starting point. This platform is a manifesto in sustainability, under which varying initiatives can take place (blueprint thought). This central platform is called: OneToZero (OTZ). This platform serves as a quality mark with clear criteria that every underlying project must meet. The core criteria that OneToZero uses is that a project:

A. Must have a scalable character regarding the energy transition
B. Must be booted from/towards an MVP (minimum viable product)

The communication and marketing tools are also designed with a blueprint idea. Various resources such as templates for social media, interactive visuals, and a concluded commercial or non-commercial video (advertisement), are assembled in a modular way and interchangeable. For example, by our 'grid' which is part of the corporate identity: when new partners/ systems are added in the future, they can be placed on the grid and be directly added to the GROHW.

Making lasting impact together: OneToZero

What is central to OneToZero is making a lasting impact together. So: get past the thoughts and realize concrete steps that really have an impact with several partners present in a consortium. We do this by presenting an attractive philosophy that creates fans and followers: because it appeals to them, strengthens them in their convictions, and offers a way to express them. Ideally, OneToZero becomes a movement, a community from which parties can also arise that participate in new or old projects: a social trend with concrete initiatives as a result, such as the local hydrogen project GROHW.

Mission/Motivation OneToZero:
'To make a lasting impact together on the road to 0 % emissions'

Together one for 0 % emissions

Climate change is a problem that concerns us all. The difference is that OneToZero does not stop at recognition alone. It is time for concrete action: we have the ambition to realize a lasting impact together. In addition, anyone who feels addressed is invited to connect with the ideas of OneToZero. Companies, professionals, administrators, or knowledge institutions who want to go a step further, can join in a consortium of an underlying project. Because taking steps in the energy transition requires chain-wide solutions. For this reason, we work together with various leaders in their own sectors, partners of OneToZero are joining forces to reduce emissions to zero using the OneToZero philosophy. The OneToZero platform offers companies, knowledge institutions, governments, and professionals the opportunity to go along and learn, GRO(H)W and work together. In doing so, companies manifest themselves as a frontrunner in the energy transition and by joining a companies' name becomes associated with 'effectively making the world in which we live more sustainable'. Thus, by contributing to lasting impact, a company also occupies a strong position within the bigger picture to set the energy transition in motion **today**.

Overarching theme as a quality mark

OneToZero is the umbrella under which any new project with related participants and based on the core criteria can be established. For example, a project can be given its own name, for example, GROHW, but be part of a larger whole with an unambiguous identity, so that lasting value is built up. The quality mark stands for expertise, proven methods, and a quality stamp for initiatives with lasting impact. In this way, we safeguard knowledge, expertise, and a valuable network with the aim of repeatable success in new initiatives to be started.

The first underlying project in which the ideas of OneToZero are expressed is Project GROHW (Paragraph 2.2).

2.2 Project: GROHW - Development of a local hydrogen system

GROHW is an example of a project which falls under the OneToZero umbrella: a consortium of various companies with sustainable ambitions. Within the GROHW consortium, we want to become more sustainable locally and affordably. GROHW focuses on developing an optimal system for the complete green hydrogen chain on a local scale: from production all the way to utilization of both Green Hydrogen, Oxygen and Waste heat. The central question is: 'How can we prevent congestion of the electricity grid with this green hydrogen system so that we can make it sustainable locally and affordably in the short term? To answer this question, we are also looking at the cost-effective use of by-products oxygen and waste heat besides the production and use of green hydrogen. Also, we investigate how we can mitigate grid congestion and we develop a digital trading platform, with which we can smartly control and trade energy flows. The city of Deventer is currently the pilot location, but this is only the beginning of GROHW. The outcome of GROHW is a scalable design that can be applied anywhere in the Netherlands or Europe at a local level: a valuable methodology, a usable blueprint, with lessons learned that allows others to go through the design phase, implementation, and operation more quickly, with fewer costs and pitfalls.

Mission: Sustainable+
Making impact in the field of sustainability by being the green hydrogen accelerator based on multidisciplinary partnerships and a scalable application.

Value proposition
A concrete and scalable practical case to accelerate the sustainable energy transition with green hydrogen as a sustainable energy carrier.

The partners and their role in the consortium
The partners within the consortium are multidisciplinary and consists of an installation company, an asphalt plant, a transport company, a start-up, a technology company, a digital marketing agency, a bank, two universities of applied sciences, and a consultancy and engineering firm.
There is enough overlap in the skills and knowledge of the partners involved to support each other, whereby the expertise differs to such an extent that a specialized partner is in the lead for each part.

3

THE BLUEPRINT METHOD

The blueprint is (a step towards) a generally applicable and efficient working method for optimal design of a system for the local production, storage, distribution and utilization of green hydrogen, oxygen, and waste heat. The choice of what is *optimal* in this context is part of the process. What is optimal is determined largely from an inventory of the possible added value of the project for potential customers and for other project partners.

The blueprint clarifies answers on the following questions:
- How do we design a system that optimally meets the starting points and objectives of the project and the various partners?
- How do we set up a business case for this design? What are the ingredients?
- What is the value proposition for the involved partners?
- How do we go through a process as efficient as possible to determine an optimal local hydrogen system?
- Which tools are needed?

To set up this blueprint, we set out by evaluating the steps that were taken in the GROHW-project in the Deventer case (Chapter 4 - The Deventer Case) from the start, early in 2020, until the beginning of 2022. We have addressed the following questions:
- What is the purpose of this process step?
- What information was produced?
- Which tools were produced and what was their added value?
- Does this process step contribute to the design process?

At this moment we have a first pilot location to base the blueprint method on. We can, however, imagine that other locations will give new insights towards the blueprint. The blueprint method should thus not be seen as definitive, but rather as a first attempt which can be shaped further when more variables are tested via other locations.

As the result of this evaluation, the steps that were found to contribute positively to the design process, are described in the next paragraphs. These steps are described as a methodology which can be used in other projects. In Appendix I a short description and evaluation is given of the other steps that were carried out, but that, in retrospect, are not thought to be useful in the methodology.

The blueprint method comprises of the following paragraphs:
1 Developing the project
2 Scoping the project
3 Designing the system
4 Electrolyser design
5 System integration
6 Trading platform
7 Business case and financeability analysis

3.1 Developing the project

Goal

The goal of paragraphs 3.1-3.3 is to develop an idea towards a general conceptual description of what the project is about and to find the right partners that should play a role in the further development of the projects. If a grant for the project is needed, the application will be prepared in this phase.

In this initial phase the basic ideas underlying the project are formulated in a conceptual project description. This description gives an answer to questions like:

- What is the main idea of the project?
  - Which additional objectives will be considered?
  - What is the possible business opportunity?
  - What is the geographical delineation?
- What stakeholders are involved?
- Which partners should be part of the consortium?
  - Project initiator(s)
  - Knowledge institutes
  - Business partners with specific technical know-how that is relevant for the project
  - Business partners that may be future customers
  - Local/regional authorities
  - Operator of the hub
  - Other stakeholders (e.g. (regional) grid operators)

Possible partners from the list can be approached to identify their interest and suitability to take part in the project. Based on their response, their willingness and capability (time and knowledge) to contribute to the project, a selection of partners is made.

If applicable, an application for project grant can be written in consultation with the project partners.

Output

The output of this step is:

- A provisional description of the project scope
- A selection of project partners
- (if applicable) an application for project grant

3.2 Scoping the project

This phase consists of the following sub-steps:

1 Exploration of technical options
2 Framing session
3 Safety and permitting assessment
4 Selection of criteria and weighting

3.2.1 Exploration of technical options

Goal

The objective of this step is to explore the possibilities and limitations of all relevant themes.

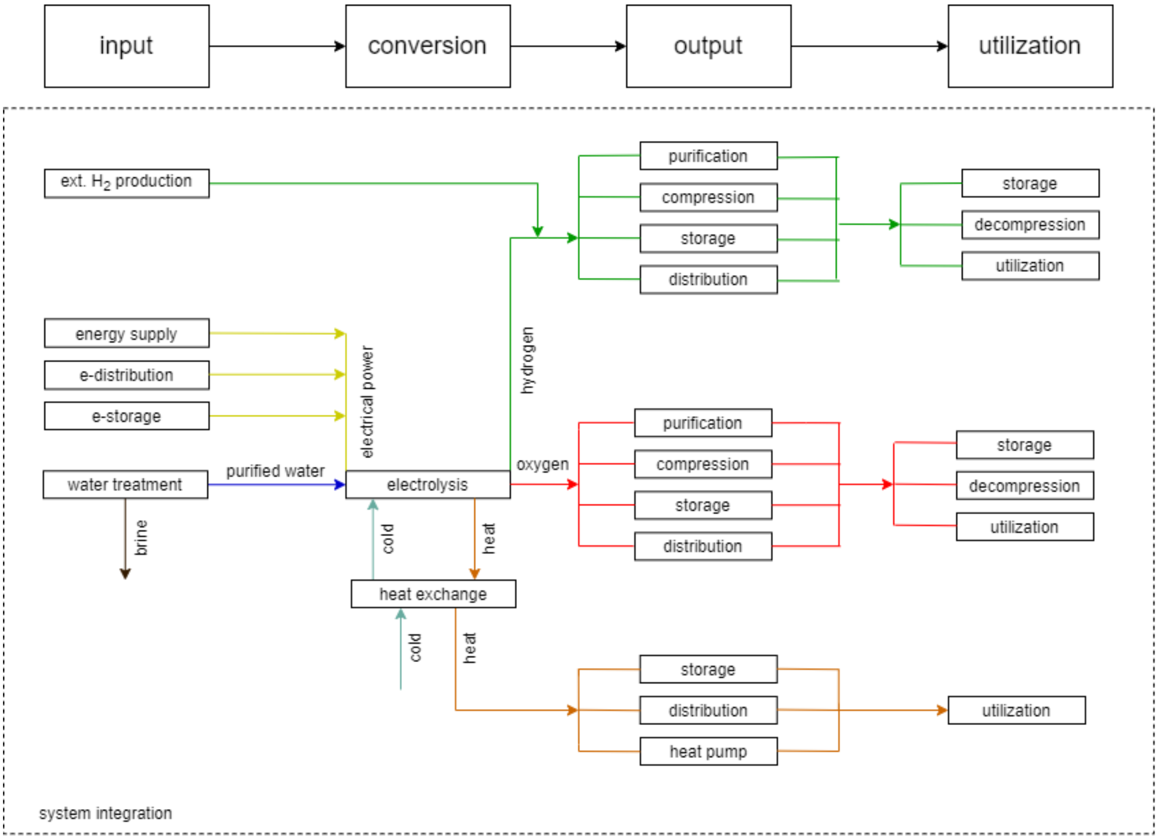
Output

This exploration is always different for each project. However, there are some outputs that help understanding any project. These are the following:

- A list of possible locations
- A list of potential customers of hydrogen, oxygen and residual heat and representative demand profiles

– A list of potential additional partners
– A list of criteria and/or requirements
– A list of potential renewable energy sources
– Energy and material balance visualized in a Sankey diagram
– A technical overview of general streams and processes as shown in Figure 3.1

Figure 3.1 Technical overview of general streams and processes (please note that only general streams are given and that the electrical power is not specifically linked to processes as purification and compression)



Tools

Excel, software to visualize the locations and costumers on a map, software to generate the Sankey diagram and software to generate a flow diagram.

3.2.2 Framing session

Goal

In a framing session the results of the technical exploration are shared with the partners to determine the scope of the project. In this session the specific interests of all partners are identified and discussed. As well as additional partners, consumers and other relevant stakeholders that play a role in the success of the project. The result is a shared idea of the objective(s) of the project and a clear division of interest and role of each partner.

This is obtained in the following steps:
– Assessment of the possible locations
– Assessment of the potential customers and partners
– The criteria and/or requirements are rated by all attendants. Additional items can be proposed and added to the list. Based on the result a distinction is made between:

    - Boundary conditions (high rating) (e.g. legislation, space limitation on site)
    - Criteria (medium rating)
    - Points of discussion (low rating; these aspects could be considered the 'nice to have's' of the project)
- Determining the technical scope based on the technical overview (Figure 3.1), the list of potential renewable sources and the energy and material balance

Output
- Locations to further consider
- Potential customers/partners to further consider
- A provisional list of requirements and criteria
- Technical scope for the different processes in Figure 3.1

Tool
An online polling tool.

3.2.3 Permitting and safety assessment

Goal
The goal of this step is to identify the required permits for the GROHW project including points of interest regarding external safety and other safety aspects. The permits are divided into six categories:
- Environment & type of establishment
- Spatial planning
- Nature
- Pipelines
- External safety
- Other safety aspects

For each of these categories, the relevant legislation is described and analysed to determine which permits are required for the project. An executive description of permits is described in Appendix II. Other safety aspects that are relevant for hydrogen projects are described in Appendix III.

Environment & type of establishment
In the Dutch 'Activiteitenbesluit' regulations for establishments are described. The regulations define three types of establishments, for which additional rules may apply:
- Type A: least environmental impact, no environmental permit required
- Type B: no environmental permit required, but additional measures may be required
- Type C: establishments that require an environmental permit (according to 'Besluit omgevingsrecht')

Besides, the European Directive on industrial emissions integrated pollution prevention and control (IPPC), (2010/75/EU) may apply as well. IPPC defines additional requirements for IPPC establishments, which are establishments that can have a (possible) negative impact on the environment.

Approach
- Determine which type of establishment is applicable for the GROHW project
- Determine if the establishment contains an IPPC installation, according to 2010/75/EU
- Determine if an environmental permit is required

Spatial planning
A hydrogen installation can only be established at a location where establishments are allowed according to the urban development plan. Otherwise, a permit for deviation from the plan is required. Within zones indicated for establishments, a distinction is made between establishments of different categories, depending on their impact on the environment. Environmental impact categories are defined in the Dutch publication 'Bedrijven en milieuzonering' (VNG, 2009).

Approach
- Evaluate if the proposed locations allow new establishments
- Determine the environmental impact category of the hydrogen installation
- Determine if the locations allow establishments of determined environmental category

Nature
Natura 2000 is a network of nature protection areas in the territory of the European Union. The development of any new project is only allowed if it does not lead to nitrogen deposition above the critical threshold value at Natura 2000 sites.

Approach
- Determine if any Natura 2000-sites are present near the proposed location
- Determine nitrogen emission and deposition resulting from GROHW
- Determine if any critical threshold values will be exceeded

Pipelines
Possibilities are investigated to transport the hydrogen by pipeline from the production site to the user's location instead of via the road. For the construction of a pipeline for transportation of dangerous compounds (including hydrogen) an environmental permit is always required according to the 'Besluit omgevingsrecht.' In addition, the 'Besluit externe veiligheid buisleidingen (Bevb) is also applicable for:
- *'Pipelines for flammable compounds with an outer diameter of 70 mm or larger, or an inner diameter of 50 mm or more, and a pressure of 1.600 kPa or more.'*

Construction is only allowed when the location is indicated as a pipeline zone in the urban development plan. If that is not the case, a permit for deviation of the plan is required. If the route crosses private properties, a 'zakelijk recht overeenkomst' or 'recht van opstal' is required.

Approach
- Determine if the 'Besluit externe veiligheid buisleidingen (Bevb) is applicable
- Determine if deviation of environmental development plan is required
- Determine if pipelines route crosses private properties

External safety
External safety is about the risk that the hydrogen system poses on its surroundings. Relevant aspects are the likelihood that an incident within the hydrogen system, such as a fire or explosion, happens (chance), and the effects that such an incident will have on its surroundings in case the incident happens (effect).

External safety risk = chance x effect

Dutch legislation regarding external safety is implemented in the 'Besluit Risico's Zware Ongevallen' (BRZO, implementation of European Seveso III Directive) and 'Besluit externe veiligheid inrichtingen' (Bevi).

Seveso III
If dangerous substances are present in quantities above a certain threshold from Annex I of the Seveso III Directive, a permit and other obligations from this directive are mandatory for the establishment (this legislation is implemented in the Dutch 'Besluit Risico's Zware Ongevallen (BRZO)). A distinction is made between lower-tier and upper-tier establishments, depending on the quantity of dangerous substances that are present. In the Table 3.1 the lower and upper tiers for hydrogen and oxygen are displayed.

Table 3.1 Threshold values for lower-tier and upper-tier establishments in the Seveso III Directive

Dangerous substance	Lower-tier requirements (tonnes)	Upper-tier requirements (tonnes)
Hydrogen	5	50
Oxygen	200	2000

Bevi
When BRZO is applicable for an establishment, this automatically means that Bevi is applicable as well. In Bevi regulations are prescribed to ensure safety distances between dangerous establishments and vulnerable objects in its surroundings, such as houses, hospitals, or large office buildings. When Bevi is applicable, a quantitative risk analysis (QRA) must be performed to determine the 'individual risk' and 'societal risk'. (In Dutch 'plaatsgebonden risico' (PR), and 'groepsrisico' (GR)). The methodology for the QRA is prescribed by the RIVM and must be performed using the Safeti-NL software. No vulnerable objects are allowed within the individual risk contours (PR 10^{-6} contours where the PR is equal to 10^{-6}). The societal risk must be justified which depends on the effect size of possible accidents with dangerous compounds and the population density around the establishment. These requirements may limit the locations that are suitable for the hydrogen system.

Approach
- Compare the amounts of hydrogen (and oxygen) present in the installation against the low/high-tier values to determine if the Seveso III directive is applicable.
- Determine if 'Besluit externe veiligheid inrichtingen' (Bevi) is applicable.
- If Bevi is applicable, perform indicative calculations to evaluate if individual risk and societal risk pose limitations on locations choice for the electrolyser and hydrogen storage.

Other safety aspects
Other relevant aspects of safety include:
- Explosion safety (ATEX)
- Process safety
- Occupational health & safety
- Relevant national or international norms and guidelines

These safety aspects are not directly applicable to the system exploration part of the project, but will be relevant in the system elaboration part. They are covered in appendix III.

Tools
- QRA
- Software Safeti-NL (external safety, risk calculations)

3.2.4 Setting up the design phase

Goal
Now that there's a clear picture of the project, its scope and its possibilities it is time to set up the design phase. This step has four goals:
1. Assess, based on expert judgement, the provisional list of criteria from the framing session to check if the criteria are relevant and distinctive. If needed, combine criteria to make a shorter and easier to understand list of criteria.
2. Determine a weighting of criteria based on the opinion of all project partners. Each partners distributes 10 points.
3. Determine the weight of each partner. For example: Each partner has an equal say in the matter.

4 Determine several design philosophies that will form the basis of the Multiple-criteria decision analysis (MCDA) A design philosophy describes what is most important for a design. For example, the most economic or sustainable design.

To involve all project partners in setting up the design phase the above steps are executed in a workshop.

Output
Weighted criteria and several design philosophies.

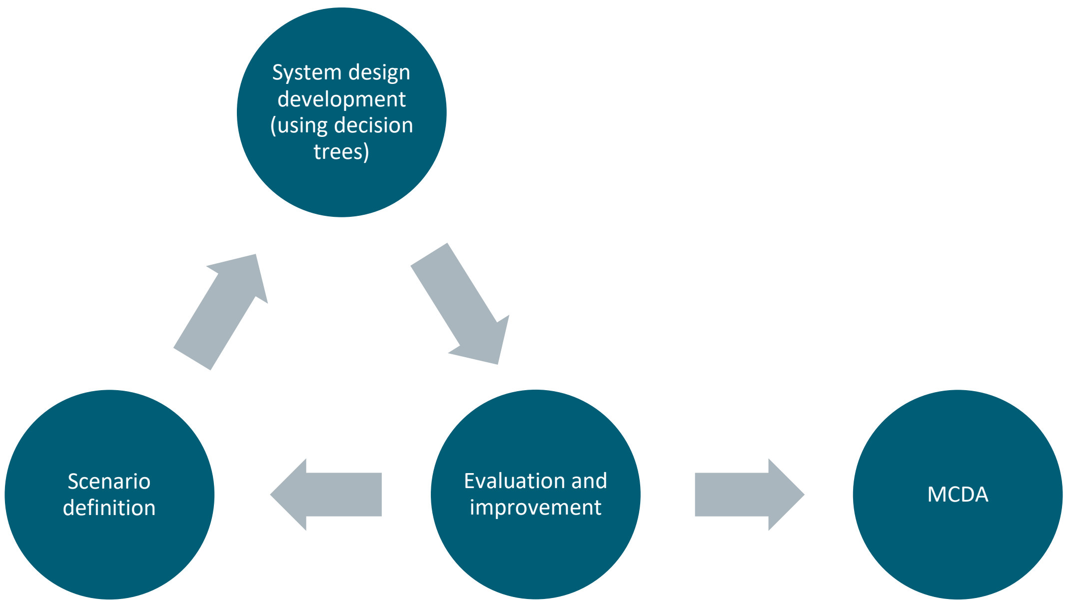
Tools
- A presentation
- A fill-in form/or polling tool for the partners to fill in their weighting
- An excel sheet to process and evaluate the weights

3.3 Designing the system

The system design starts with defining a scenario. A scenario is a technical translation of the results of the framing session and weighing of the criteria. Based on a scenario, a system design option is developed with the help of decision trees. Figure 3.2 illustrates the development of a scenario into a system design option. In many cases this is an iterative process. The system design is then evaluated and the scenario is improved where needed resulting in an iteration on the system design. The iterations are repeated until the resulting system design option is good enough to consider in the Multiple-criteria decision analysis (MCDA) that is conducted with all project partners. During the MCDA one system design is chosen which forms the basis for the next part: system elaboration. In this next phase the following topics will be addressed: engineering of the electrolyser and storage, system integration (engineering of the system), trading platform and business case and financial analysis. At this moment, this next phase is out of scope of this report.

The next paragraphs further discuss each step of the system design process.

Figure 3.2 Iterative design process



3.3.1 Scenario definition

Goal
The goal of this step is to define scenarios that form the basis for the development of system design options. A scenario is based on a design philosophy (or 'perspective'), production location and potential user (profiles).

Output
A scenario consists of the following elements:
- The design philosophy, which describes the most important motivator for the design. (For example: sustainability, cost effectiveness, flexibility, and security of supply).
- The location(s) of the production facility (this determines the available capacity of existing electrical infrastructure and renewable energy sources).
- Potential hydrogen customer(s) for each location (this determines the distance by pipeline below sealed surfaces and non-sealed surfaces to the production location).
- The hydrogen demand profile for each potential customer.

The characteristics of a scenario should be independent, not following from technical considerations based on other characteristics of the scenario. Scenarios must be distinctive so that there is something to choose from in the next phase.

Tools
This step is documented by an Excel overview.

3.3.2 System design development

Goal
The goal of this step is to develop scenarios into system designs. The level of detail in the outcome of this system design is chosen in such a way that there is sufficient information to start the system elaboration part without making premature decisions, while being able to make a substantiated choice for the system.

The system designs are input for the MCDA as described in the next paragraph.

Output
For each scenario, a system design is developed which is characterized by the following elements:
- The type of electrolyser (proton exchange membrane (PEM) or Alkaline). These two types of electrolysers are currently commercially available at MW-scale
- Installed power of the electrolyser
- Full load hours of the electrolyser
- Basic control strategy of the electrolyser (i.e. based on hydrogen demand or following renewable energy sources)
- Hydrogen consumption profiles of customers within scope
- An indication of hydrogen storage capacity (small/large)
- Hydrogen transport method for each customer, by road or pipeline
- Electrical infrastructure requirements
- An indication of electrical storage capacity and power
- Type of oxygen utilization
- The maximum distance from the production location to the residual heat user which is still feasible for a positive business case

As stated before, some decisions are not made in this phase because they do not affect which system design option is chosen. This includes the following parameters:
- Hydrogen storage and distribution pressure. We know that compression and pressurized storage and transport is always necessary. In this phase, we do not have sufficient information to determine the

optimal pressure. Furthermore, we do not expect it to be a distinguishing factor between design options. Therefore, we determine the optimal pressure in the next phase.
- Hydrogen purification. Hydrogen purification needs to be performed but does not have a distinguishing effect on the system design choice.
- Specific details on utilizing oxygen and residual heat. In this phase we do not have sufficient information to make detailed decisions. Furthermore, these specific details are not a distinguishing factor between the design options. Therefore, we only make a high-level decision in this phase.
- Feed and wastewater treatment. The specific details for treatment are assumed not to be a distinguishing factor between the design options.

Tools

From a scenario, a system design is developed. This design process comprises decisions and calculations that are standardized in this blueprint approach. It is captured in decision trees. Each decision tree corresponds to a process as shown in Figure 3.1.

Not every process has a decision tree, because not every decision has a distinguishing effect on the system design.

The system design process is guided by decision trees to develop a scenario into a system design. Because most decision trees use output from other decision trees, the order in which the decision trees should be followed is such that as little dependencies as possible are needed in advance. Table 3.2 shows the decision trees and the order in which they should be executed from starting to end point. Furthermore, it is necessary to go through all decision trees to generate the required output for a system design option.
The decision trees itself and details on each decision tree can be found in Appendix IV.

Table 3.2 Decision tree overview (in the order they should be performed).

Decision tree	Input from scenario	Input from other decision trees	Output
Hydrogen transport	– Hydrogen production location(s) – Potential hydrogen consumption profiles and its location	n.a.	Hydrogen transport method per potential customer. If the decision is not clear cut, a decision cannot be made in this phase
Electrolyser	– Design philosophy	n.a.	– Electrolyser type – Full load hours[1]
Hydrogen utilization	– Potential hydrogen consumption profiles – Hydrogen transport method per potential customer	– Hydrogen transport method – Full load hours	– Hydrogen consumption profiles within scope – Indication of hydrogen storage capacity
Oxygen	– Location(s) – Design philosophy	Hydrogen transport method	Feasibility of oxygen utilization
System integration	n.a.	– Electrolyser type – Full load hours – Hydrogen consumption profiles within scope	Electrolyser power for each location
Electrical distribution	– Location(s) – Design philosophy	Electrolyser power	Electrical infrastructure requirements

[1] Full load hours is defined as the equivalent number of hours that the electrolyser operates at nominal power (the energy consumption of the electrolyser equals the amount of full load hours multiplied with the nominal power).

Electrical storage	– Location(s) – Design philosophy	– Electrical infrastructure requirements – Electrolyser power – Electrolyser type – Hydrogen consumption profiles within scope	Indication of electrical storage capacity and power
Residual heat	– Location(s)	– Electrolyser power – Electrolyser type – Full load hours	Radius to consider off-take for residual heat.

3.3.3 Evaluation and improvement

Goal

Part of the data from the scenario together with part of the output generated in the decision trees, creates a system design option as defined in the previous paragraph.
This system design option is evaluated against the criteria as defined in paragraph 3.2.4.. A design option does not have to be the best all-round option. But it should be a good option for the design philosophy it is built on to make sure that there are distinctive system design options to choose from for the MCDA.

As stated before, the system design is an iterative process which means that the first iteration will probably not yield the best system design option. Therefore, it needs to be improved. This is done by judging the results and changing the scenario in such a way that it will improve. Some examples that could improve a scenario:
- Changing the production location
- Changing the control strategy to get to different full load hours
- Changing hydrogen consumption profiles, for example by delivering up to a certain capacity

Basically, anything can be changed except the design philosophy.

System designs are usable for the MCDA if they score well on the criteria that relate to its design philosophy, if the options are distinctive between each other and if the outcomes of the decision trees are feasible. Keep in mind that the outcome of the MCDA can also be a hybrid between multiple system design options.

Output

There are two possible outcomes of this step:
1. A redefined scenario to develop a new system design option
2. A system design option to be evaluated in the MCDA

Tools

The decision trees give an indication of the quality of the result by colour coding and the same tools used in the MCDA can be applied. See the next paragraph.

3.3.4 Multiple-criteria decision analysis (MCDA)

Goal

The goal of the multiple-criteria decision analysis (MCDA) is to determine the definitive system design option that will be the starting point for system elaboration part.
To achieve this goal, the following steps are taken:
- Each criterion (determined in paragraph 3.2.4) is scaled so that they can be compared. For example, both costs and sustainability should be scored on a scale of one to five. These scales must be chosen in such a way that there will be different scores between the system design options.
- Each system design option is scored on the criteria.
- The weights that all the partners have given to the criteria must be combined into one representative weight. This can be done in different ways, depending on the stakeholders in the project. For example, by

taking the average of all the weights the partners have given or the weighed (based on investment in the project) average of all the partners.
- Based on the weights of criteria, each system design options receives a single weighed score.
- The results of the MCDA are shared with all partners. All partners are advised to study the results and address any concerns there might be before a plenary session.
- In a plenary session with all partners the outcome is discussed. It's important to remember that an MCDA is only a tool to make decisions and assess the sensitivity to the assumptions that are made.
- Based on the above results a system design option is selected by qualitatively assessing the results of the above steps. This could also be a hybrid of the initial system design options.

Output
A single system design option is characterized by the elements described in paragraph 3.3.2, which constitutes input for the system elaboration part.

Tools
An excel sheet to score the system design options on the criteria, weigh the criteria, and determine the final score of the system design options.

3.4 Electrolyser design

Two PEM electrolysers are designed for this GROHW project: resulting in a 1 MW and a 2 MW electrolyser design, where besides hydrogen also oxygen and waste heat can be utilised from. For the blueprint it was investigated if (and which) one of these electrolyser designs could function as a building block and for which purpose.
The following goals of a design as a building block were explored:
- **To increase capacity:** e.g. using the 1 MW design twice to result in 2 MW capacity by repeating two 1 MW building blocks. Unfortunately, it was found that is more efficient to use the 2 MW design rather than 2 times the 1 MW design, because the components can be used more economical, for example a separator is nearly the same size, and the sensors and control are the same for 1 or 2 MW. Here modularity is thus not beneficial. Going to higher capacities of the building blocks may end up becoming more modular, but this was not investigated in this project.
- **To increase flexibility:** e.g. producing a 750 kW or a 1250 kW electrolyser, with the same 1 MW design. It was found that the 1 MW design can easily be used to change capacity, as only the number of cells in a stack need to be reengineered. This way the 1 MW design can flexibly be fit depending on the specific user demand/electricity input.
- **To increase repetition**: e.g. using the exact same design for a project in a different location. 1 MW and 2 MW capacity are quite common capacities if a hydrogen project on local scale is developed. Both designs are designed such that it is easy to select if utilisation of oxygen/ waste heat is also needed. This makes the design applicable to many local projects.

The following (system)components are economy of scale, thus more economical beneficial if capacity needs to be increased:
- Water purification unit
- Oxygen/water separation
- Hydrogen/water separation
- Cooling
- Hydrogen purification

The following components are economy of number, thus more economical beneficial flexibility/repetition is increased:
- Transformer / Rectifier
- Electrolyser stacks
- Basis of design (BoD)

3.5 System integration

The Basis of Design and Equipment list that are composed for the Deventer case are relatively generic and can therefore be applied for other locations without much effort. The main input parameters for the system integration design are defined by the electrolyser system and not so much by the location. Therefore, the system integration installation is largely reproducible for other locations. Location-specific aspects that need to be considered for the system integration design are:

- Grid operator and grid connection possibilities.
- Hydrogen and oxygen demand in the area: both the consumption demand, the distance from the hub and the pipe routing options are factors that play a part in choosing the distribution method.
- Residual heat consumption: in the Deventer case this is not a viable option, but this is something that could be considered in other situations.
- Based on the environmental safety requirements and regulations the design may have to be adjusted. The system might have to be placed inside of a building instead of a container for example, or other additional safety or regulatory measures need to be taken, depending on the location. It must be noted though that the hub is designed to be inherently safe according to the general Dutch safety regulations. Location-specific requirements may also be applicable to obtain the permit, such as specific noise requirements.

Besides the difference due to location, there could be a difference in scale of the hydrogen energy hub. In this project a 2 MW electrolyser was selected. However, if more consumers could be found, a differently sized electrolyser could be selected. The economies of scale factor indicates how the costs of the different systems will vary depending on the scale of the system. This *economies of scale* factor can generally be assumed to be 0.8 in this project, except for the stacks. Usually, the costs per MW become lower as the size of the installation increases due to more efficient use of the installations and discount prices for bulk buying, among other factors. The economies of scale for the stacks are uncertain though, because the material it is made of is a rare material and the global demand for stacks is increasing rapidly. Consequently, the price of the stacks varies heavily. This uncertain future pricing makes it impossible to determine the economies of scale for the stacks. Manufacturers are not always able to produce as much stack material as is needed for larger scales either, which impacts the economies of scale as well.

3.6 Trading platform

3.6.1 Goal

The trading platform registers and orchestrates energy flows through a trade-mechanism. It serves as a market layer between renewable energy sources, the electrolysers, hydrogen consumers and the electricity grid. This enables communication between participants and ensures fair prices for the produced electricity and hydrogen. The market layer is designed by clever alignment of production, consumption, storage, and network capacity.

The market will work decentralized, meaning that every participant will make and execute their own trade-decisions. Also, to serve the *flexible system design* the platform will work with hydrogen and electricity; hence it is called a *decentralized multi-energy trading platform*.
In addition, the platform visualises the energy flows. This enables the participants to gain further insights and develop further optimizations.

In summary, the trading platform's goal is threefold:

1. Measure and register energy demand and supply
2. Match demand and supply through a trade-mechanism
3. Visualize energy flows

3.6.2 Research

Based on the project scope, the following research-questions were answered:
- Regulatory: the system must function within the regulatory framework of the Netherlands.
  - How and on what markets can electrolysers enter the electricity market?
  - How are direct connections with renewable energy sources legally possible?
  - Can electrolysers help with grid balancing?
  - What are the laws and standards on hydrogen trading?
- Green:
  - Is it mandatory for the system to use only green electricity for the creation of hydrogen?
  - How are green energy certificates traded now?
  - To which types of energy do certificates apply?
  - What are the future developments for certificates trading?
- Technical:
  - What are additional elements (storage tanks, pressurizers etc.) and what is their impact on the efficiency of the system?
  - Are there hard constraints for the system to keep running?
  - Which methods can the system use for interfacing with the participants (solar park, electrolyser)?
- Flexibility: the system must be able to profit from fluctuations in electricity prices and hydrogen demand.
  - How can electrolysers use dynamic prices when buying green electricity?
  - To what extent can hydrogen consumers be flexible in their demand?

These questions were answered through literature research and conducting interviews with GROHW stakeholders. In addition, an interview with the Dutch TSO was conducted.

Furthermore, simulations were developed and performed to answer these questions:
1 To what extent can the initial proposed system of GROHW run on self-consumption? (Q1)
2 What is the most optimal size of hydrogen storage for the initial proposed system and to what extent can it increase the self-consumption? (Q2)
3 What effect do dynamic prices have on the most optimal size of hydrogen storage and the self-consumption? (Q3)

For these simulations, (historical) data is needed from the participants: generated energy (solar farms, wind turbines), electricity to hydrogen ratio (electrolysers), expected usage from participants and additional elements (such as storage).

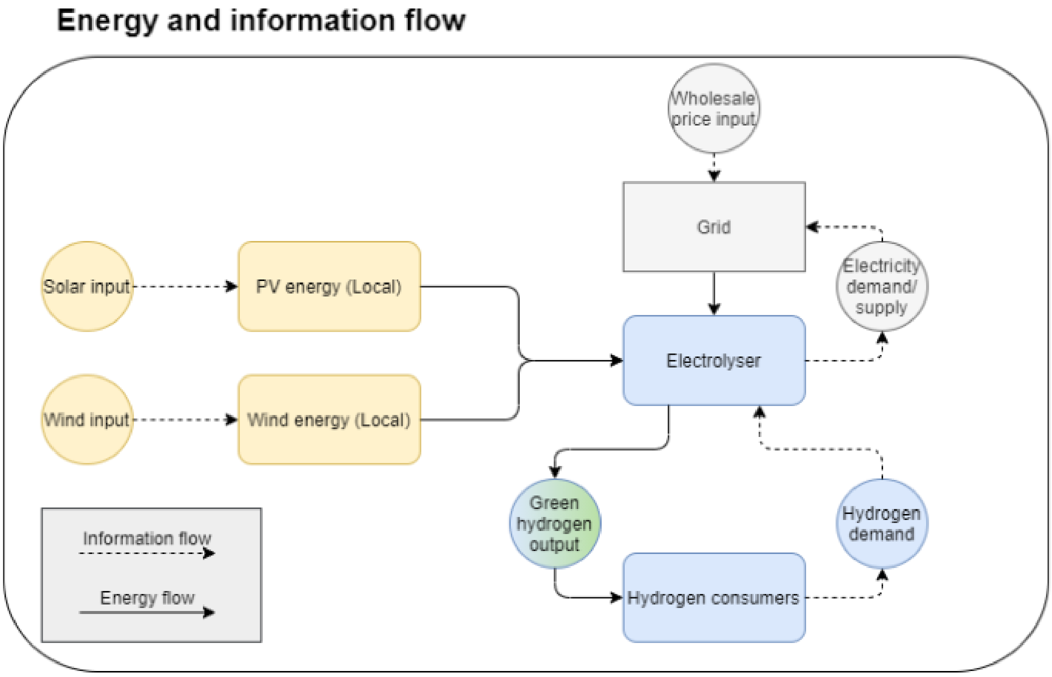
3.6.3 Platform design

Figure 3.3 gives a schematic overview of the energy and information flows of the system, which can be used as a blueprint for other projects.

Every participant obtains access to the trading platform through a device connected to their installation (electrolyser, solar park etc.). This device contains software for participating on the trading platform. This software is called an *agent*. Therefore, every participant is represented by their own agent that trades energy on their behalf. The information architecture identifies three types of agents throughout the system:
1. **Consumer agents**: determine and publish the required amount of energy
2. **Producer agents**: control the production of energy (e.g. the electrolyser), based on the required amount of energy over time
3. **Storage agents**: measures the amount of stored energy

In addition, external data-sources (for example: weather-data) are available for the agents to make more informed decisions. As such, the trade platform uses decentralized decision-making, based on information shared inside the network of the trading platform, resulting in a more flexible and solid system. This also allows the usage of blockchain-technologies (a distributed ledger), which enables a secure and reliable registration of energy-transactions.

Figure 3.3 Generic overview of energy and information flow for the flexible system design



3.7 Business case and financeability analysis

The Deventer case has a positive business case if it delivers the hydrogen and oxygen in small cylinders at unit prices of € 10/kg (hydrogen) and € 0,07/kg (oxygen) because of the proximity of Westfalen's distribution hub. However, this is not an easily repeatable sales channel. Both the distance to Westfalen and the saturation of this channel will be limiting factors for other projects. Optimal local offtake options should be considered for each project individually, since the hydrogen sales price is the most important factor determining the outcome of the positive business case.

Since financing of a new technology provider is more risky and therefore more difficult, it is recommended to explore the market for technology providers with a more proven track record.

To aid in the process of analysing the business case of a potential location quickly, Witteveen+Bos is creating a web-based business case tool that enables users to enter location specific parameters, resulting in a quick-scan business case calculation. By including a scaling factor for the various parts of the electrolyzer system, it will be possible to assess the business case of various system sizes. Most parts have a scaling factor of 0,8 with the exemption of the stacks that don't show scaling benefits.

4

THE DEVENTER CASE

The Deventer case comprises of the following paragraphs:
1 Developing the project
2 Scoping the project
3 Designing the system
4 Electrolyser design
5 System integration
6 Trading platform
7 Business case and financeability analysis.

4.1 Developing the project

This paragraph covers the project description, the involved partners, and the grant proposal.

Project description

The municipality of Deventer has the ambition to become energy neutral by 2030. To achieve this goal, sustainable energy production must increase. However, the power grid around Deventer is becoming too congested which makes it impossible to further increase sustainable energy production. Furthermore, simply producing more sustainable energy will not decarbonize high-temperature industrial processes and the transport sector.

This is where GROHW comes in. A local green hydrogen hub alleviates grid congestion, allowing for more sustainable energy production, and production of green hydrogen to decarbonize industrial processes and the transport sector. This locally produced green hydrogen must be competitive compared to future green hydrogen produced on a large scale.

Project partners and stakeholders

The project is executed by the following partners (Figure 4.1):
- Project initiator(s):
  - Witteveen+Bos
- Knowledge institutes:
  - Saxion Hogeschool
  - HAN University of Applied Sciences
- Business partners with specific technical know-how that is relevant for the project:
  - MTSA Technopower
  - Rabobank Salland/NL
  - HanzeNet (located at the Gasfabriek)
  - Brandeniers
- Business partners that may be future customers:
  - Van Dorp
  - Vos Transport
  - AsfaltNu

· Koninklijke Auping (Auping ended partnership during the project, as they also explored other sustainability routes than via hydrogen and a different route was selected. However, some information was used for the system design)

Figure 4.1 Geographical overview of partners and selected stakeholders

Furthermore, the following parties are stakeholders in this project:
- S/Park, as a potential location
- Enexis, the regional grid operator
- Nefit Industrial, as a potential customer of hydrogen and oxygen
- The municipality of Deventer
- Gasfabriek
- Business Park A1
- Stichting DEP
- Omgevingsdienst IJsselland
- Oost NL
- Clean Tech Regio
- Provincie Overijssel
- HVE
- Cool

The consortium does not have a potential operator nor a fuel station owner in its consortium.

Grant proposal
The grant proposal with reference number 2020/0157314 was prepared for and approved by the Provincie Overijssel.

4.2 Scoping the project

This phase consists of the following sub-steps:
1. Exploration of technical options
2. Framing session
3. Safety and permitting assessment
4. Selection of criteria and weighting

4.2.1 Exploration of technical options

This paragraph covers the exploration of possible locations, potential customers (partners), renewable energy sources and the heat and mass balance.

Possible locations
The following locations are considered:
- S/Park. This location seems the most suitable because it already has industrial infrastructure in place and there is space for an additional facility.
- A1 business park, where there are plans for a hydrogen fuel station. Further referred to as A1 fuel station.
- Locations of project partners and/or potential customers:
  - AsfaltNu
  - Nefit Industrial
  - The wastewater treatment plant of Deventer
  - Vos Transport
  - Koninklijke Auping
  - Gasfabriek

See appendix V for further details on the selection of locations.

Potential customers and partners
The following potential customers and partners are considered. This is based on the knowledge the consortium has about the businesses in Deventer:
- Potential customers and/or partners listed before:
  - AsfaltNu for hydrogen and potentially oxygen
  - Van Dorp for hydrogen
  - Koninklijke Auping for hydrogen
  - A potential hydrogen fuel station at the A1 business park that provides hydrogen to Vos Transport, Van Dorp, and others
  - The Gasfabriek for waste heat
  - Nefit Industrial for hydrogen and potentially oxygen
- The wastewater treatment plant for oxygen consumption and possible production location.

Based on the received data and additional assumptions, hourly hydrogen demand profiles are generated. The Table 4.1 gives an overview of this:

Table 4.1 Overview of hydrogen demand.

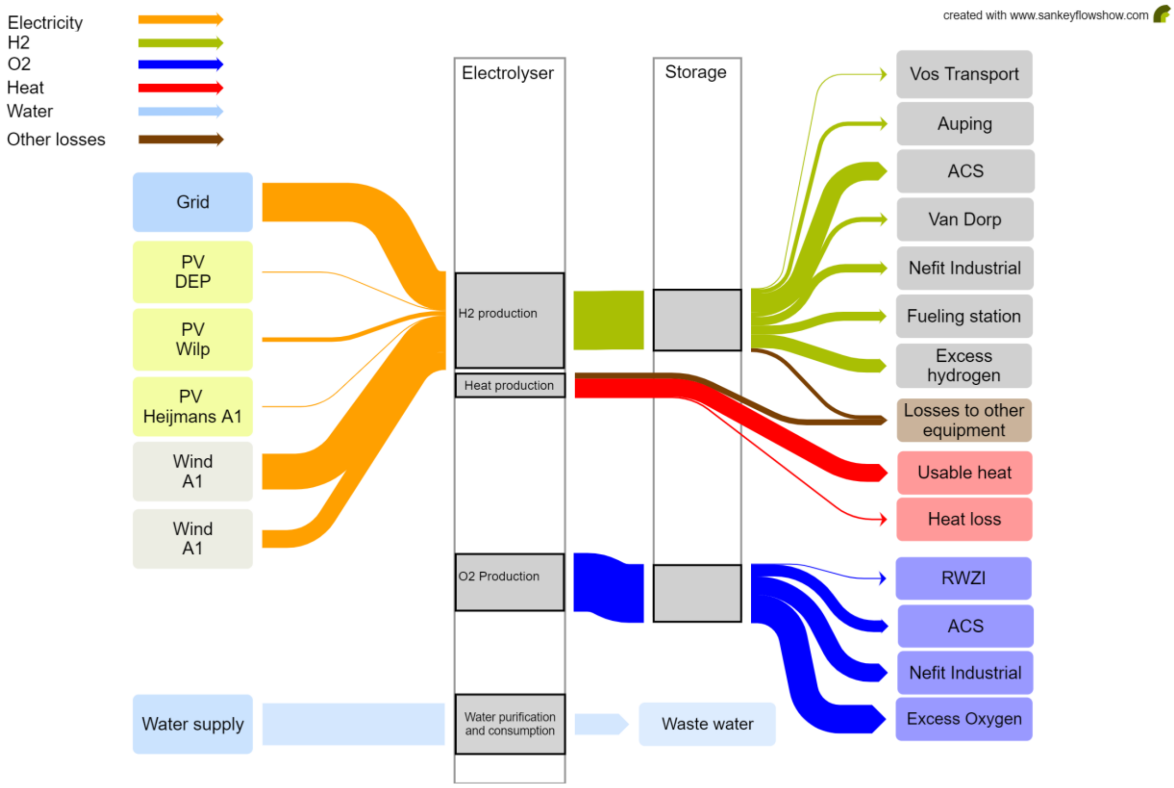
Potential customer	Received data	Assumptions	Total hydrogen demand (ton/y)
AsfaltNu	Hourly gas demand that is to be replaced with hydrogen from 2018	n.a.	~120
Van Dorp	100 000 Nm^3/y for heating of offices	Gas consumptions is modelled using a standard gas consumption profile for 2018 applicable for large consumers up to 175 000 Nm^3/y (NEDU, sd). Additionally, the temperatures from the weather station in Heino of 2018 are used (Koninklijk Nederlands Meteorologisch Instituut, sd).	~25
Koninklijke Auping	Monthly gas demand from 2019	Each month has one average hourly demand	~20
A1 fuel station	n.a.	150 kg H_2/day	~55
Nefit Industrial	Monthly gas demand from 2018	Each month has one average hourly demand Except for August where there is a 16-day summer stop.	~330
Gasfabriek	No data received	n.a.	n.a.
Wastewater treatment plan	No data received		

For all cases except the fuel station, the hydrogen demand assumes that hydrogen supplies the same energy content as natural gas.

Potential renewable energy sources
The following sources of renewable energy sources are of interest in Deventer:
- Solar PV from Deventer Economisch Perspectief
- Solar PV in Wilp
- Solar PV from Heijmans near the A1
- Two wind energy projects near the A1

Heat and material balance
The energy and material balance over a year is visualized in the Sankey diagram in Figure 4.2. The numbers are left out because they have changed over the course of the project. The figure servers as an indication and helps to understand the general scope of the project. In this Sankey diagram the additional energy for storage and distribution purposes is not shown.

Figure 4.2 Sankey diagram of the energy and balance (excl. energy needed for storage and distribution)



4.2.2 Framing session

This paragraph covers the results of the framing session:
- The possible locations, potential customers, and technical scope to be considered in phase 3: system design is determined
- If applicable, the need for additional partners is identified
- Criteria and/or requirements are identified
- Technical scope

Locations

The following four locations are considered after the framing session:
- S/Park
- A1 fuel station
- ASFALTNU
- Nefit Industrial

See appendix V for further details on the selection of locations[1].

Potential customers and partners

All potential customers are further considered except the wastewater treatment plant. The wastewater treatment plant didn't show sufficient interest and is geographically far away from the other locations.

We recommend including an operator in future projects in the consortium. An operator adds valuable practical knowledge and is a key stakeholder to consider when designing and financing the system.
A sustainable energy developer is left out intentionally within this consortium, as this gives freedom in eventually selecting the best match for the developed project scope.

[1] Note that we have executed a separate session for the selections of locations. However, we believe it is better to make this part of the framing session in future projects.

Requirements and criteria

During the framing session, all partners have been asked to rate whether a subject is considered as a strict project requirement or a criterion on which to assess different design options. The table below shows the results.

Table 4.2 Requirements and criteria

Topic	Requirement/Criterion
Safety and permitting	Requirement
Footprint	Requirement
Security of supply	Requirement
Scalability	Requirement
Grid stability	Requirement
Knowledge development	Requirement
Response time	Criterion
NO_x-emission	Criterion
Efficiency	Criterion
Lifetime	Criterion
Flexibility	Criterion
Business case	Criterion, only if the business case is positive
CO_2-emissions	No clear decision
Technology readiness level (TRL)	No clear decision
Social acceptance	No clear decision

Technical scope

Furthermore, the technical scope for the processes in Figure 3.1 has been discussed. The table below shows which technical solutions are in the scope of the project for different processes.

Table 4.3 Technical scope for selected processes

Process	Technical scope
Energy supply	Green energy from the grid, windmill, and solar PV (on roofs)
e-distribution	Grid connection and/or AC microgrid
Electrolyser	PEM or alkaline
External hydrogen production	Purchase of green hydrogen
Hydrogen distribution	Existing gas infrastructure, new infrastructure, and transport by road
Hydrogen storage	Pressurized tanks above and below the surface and bottles
Hydrogen utilization	Industrial use, heating of buildings and offices and mobility
Oxygen distribution	New gas infrastructure and by road
Oxygen storage	Pressurized tanks above ground and bottles
Oxygen utilization	Water treatment, in steel production and reduction of NO_x-emissions
Residual heat	In scope

4.2.3 Safety and permitting assessment

Environment
Part of the GROHW project is storage of hydrogen and possibly of oxygen as well. This means that an environmental permit is required according to the 'Besluit omgevingsrecht', annex I part C. The following categories are applicable:
- Production of hydrogen, to produce dangerous compounds
- Storage of hydrogen in tanks (when hydrogen is stored in cylinders, this category is not applicable)
- Storage of oxygen, but only when the volume that is stored is larger than 100 m^3 and oxygen is stored in tanks

The EU IPPC directive is applicable for the GROHW project, category 4.2:
Production of inorganic chemicals, such as:
(a) gases, such as ammonia, chlorine or hydrogen chloride, fluorine or hydrogen fluoride, carbon oxides, sulphur compounds, nitrogen oxides, ***hydrogen****, sulphur dioxide, carbonyl chloride;*

Concluding: to produce hydrogen and oxygen a permit application for type C (IPPC) establishments is required. For the storage of hydrogen (in tanks) a permit is required as well. For the storage of oxygen, a permit is required when oxygen is stored in tanks, and when the volume that is stored is larger dan 100 m^3. If these activities take place at a location that already has an environmental permit, which is the case for S/Park, an 'wijzigingsvergunning' (modification of the permit) is required (see also Spatial planning).

Spatial planning
According to the publication 'Bedrijven en milieuzonering'[1], the electrolyser is most likely to be assigned to environmental impact category 5. In that case, the electrolyser is only allowed in zones that are indicated for this category in the urban development plan. An overview of the urban development plans and the allowed impact categories is listed in the table below.

Table 4.4 Overview of urban development plans for possible locations for GROHW.

Location	Urban development plan	Maximum allowed environmental impact category
S/Park	Bergweide, Kloosterlanden - Hanzepark, Veenoord	Chemical companies, category 5.2
Nefit Industrial	Bergweide, Kloosterlanden - Hanzepark, Veenoord	5
AsfaltNu	Bergweide, Kloosterlanden - Hanzepark, Veenoord	4
Business park A1	Chw A1 bedrijvenpark 2020	3.2

At this moment, an establishment of category five is only allowed at S/Park and Nefit Industrial. At S/Park, chemical plants of category 5.2 are explicitly allowed. However, for both locations exceptions are defined, stating that the following establishments are not allowed:
1. Establishments mentioned in parts C and D of the annex to 'Besluit milieueffectrapportage'
2. Bevi establishments, accepts for the already existing

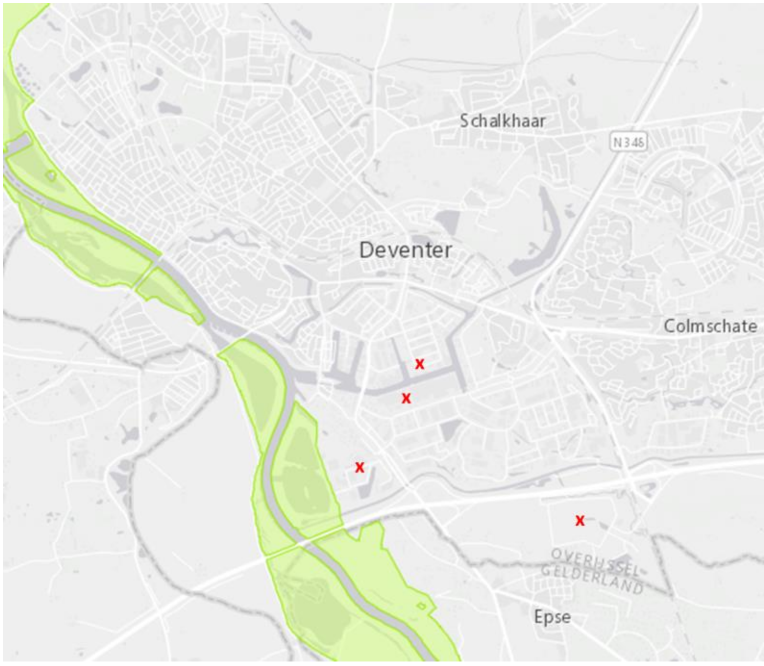
The first criterium applies to the GROHW project. The second criterium possibly applies, as is explained in the paragraph 'External Safety' below. Therefore, a permit for deviation of the urban development plan may be needed.

[1] https://vng.nl/onderwerpenindex/ruimte-en-wonen/omgevingswet/publicaties/handreiking-bedrijven-en-milieuzonering

Nature

The Natura 2000-areas surrounding Deventer are shown in green in Figure 4.3. The four possible electrolyser locations are shown with a red cross. Thus, the proposed locations for the electrolyser are close to Natura 2000-areas and nitrogen deposition may present a risk for the project.

Figure 4.3 Natura 2000 sites (green) around Deventer and four possible electrolyser locations (red cross)



It is expected that the construction of the facilities and the production of hydrogen will not cause a significant nitrogen deposition on Natura 2000-sites. The transportation of hydrogen with trucks will lead to NOx emissions, but the emission of freight traffic is usually limited.

The use of hydrogen as a fuel will lead to NOx emissions, and it is likely that part of this emission will lead to deposition on nearby Natura 2000-sites. Using hydrogen as a fuel will at the same time substitute natural gas which also emits NOx, and this NOx emission is already permitted. Therefore, the NOx deposition due to the use of hydrogen can partly be exchanged with the current NOx emissions from natural gas. The exact nitrogen emission and deposition will have to be evaluated in a later stage of the project.

Pipelines

For hydrogen pipelines, an environmental permit is always required. The 'Besluit externe veiligheid buisleidingen (Bevb) is probably also applicable for this pipeline(s), as it is expected that the pipeline will have an outer diameter larger than 70 mm. The route to the users will have to cross areas that are not marked as pipeline zones in the urban development plan, so a permit for deviation of the plan is required. It is likely that the route will also cross private property, in which case a 'zakelijk recht overeenkomst' or 'recht van opstal' is required as well.

Other permits

In addition to the permits described above, a building permit is required as well. Depending on the selected location, the environmental development plan may also define requirements regarding archaeology or environmental or soil studies. However, these permits are simpler to acquire than the ones described above, and the procedure time is much shorter (weeks instead of months). Therefore, they are not discussed here, but will be investigated at a later stage when more details about the hydrogen installation are available.

External safety

Seveso III

When a scenario with one central storage location is selected, and a less flexible production scenario is chosen, a relatively large amount of hydrogen must be stored at that location to fulfil all demands. In that case, the lower-tier threshold value of 5000 kg from the Seveso III guideline may be exceeded. This means that in that case, a permit and other obligations from this directive are mandatory. These are described in more detail in Appendix III. This also means that Bevi would be applicable.

Bevi

Of the proposed locations, only S/Park currently has the required permits for a Bevi establishment.

In this phase, sufficient information about the system isn't available to perform reliable risk calculations. Therefore, a QRA has not yet been performed, but will be part of the system elaboration part when more details about the system design are available. Information that is required for the QRA includes:

- Amount of hydrogen that is present in the system
- Storage method (type of container (tanks, vessels, cylinders) number of vessels, volume of the vessels, pressure)
- Frequency and duration of loading activities
- Equipment used for loading activities (such as loading pipe length and diameter, volume, and pressure of the transportation vessel)

Preliminary risk calculations based on the assumptions described in paragraph 2.2.3 indicate that the risk contours will probably fall inside the site boundaries of all locations. Therefore, this will probably not exclude any of the proposed locations. However, these are just indicative calculations based on assumptions that may possibly change.

For hydrogen fuel stations and hydrogen utilisation at the companies, safety distances and guidelines for safe design, construction and operation are prescribed in PGS 35. At the moment, these are, however, out of scope of this project: the hydrogen is assumed to be delivered to the door.

Other safety aspects

Relevant aspects are covered in appendix III.

4.2.4 Setting up the design phase

Now that there’s a clear picture of the project, its scope, and its possibilities it is time to set up the design phase. This paragraph discusses the criteria and their ratings and the design philosophies that form the basis for the system design development.

Criteria

Based on the results from the framing session, five criteria have been selected to assess the system design options. The table below shows these criteria and which topics are related to it.

Table 4.5 Criteria selection

Criteria	Description	Related topics
Capital expenditures (CAPEX)	The initial investment costs	Business case
Production costs	This is defined as the CAPEX plus 10 years of operational expenditures (OPEX) per kg of produced hydrogen	Business case
Sustainability	This is defined as the avoided CO2-emissions compared to the use of natural gas and/or diesel based only on the energy content of the energy carriers (the efficiencies are assumed to be the same). CO2-emissions during construction and operation of the hydrogen hub are not considered	CO_2-emission
Operability	This criterion assesses how hard or easy the system is to operate	Response time, lifetime
Flexibility and multifunctionality	This criterion assesses how easy a system design is to adjust in the future and/or if it is multi-functional	Scalability, grid congestion[1], NO_x-emission, flexibility

The following topics are strict requirements for all system design options:
- Safety and permitting
- Security of supply
- Grid stability

Finally, some topics are not considered at this stage yet because this requires more details:
- Physical footprint
- Knowledge development
- Efficiency
- Technology readiness level (TRL)
- Social acceptance

Rating the criteria
To compare different criteria, all the partners score the importance of the criteria by dividing 10 points over them. The rating of each partner is then multiplied by their relative investment (in time and/or money) in the project to come to a total rating. Finally, this rating is normalized on a scale of 0 - 100 %. Table 4.6 shows the final results of this process.

Table 4.6 Rating of criteria

Criteria	Relative importance
CAPEX	14 %
Production costs	**27 %**
Sustainability	16 %
Operability	**27 %**
Flexibility and multifunctionality	16 %

[1] Grid stability is defined as a requirement in Table 4.2 Requirements and criteria. This is translated into grid stability as a requirement and grid congestion as part of a criterion.

Production costs and operability are considered the most important as they both receive a score of 27 % importance. CAPEX, sustainability, and flexibility and multifunctionality are considered less important (14-16 % importance).

Design philosophies

Based on these criteria and their rating four design philosophies are developed. The table below shows these design philosophies and the criteria they are based on.

Table 4.7 Design philosophies

Design philosophy/ Criteria	CAPEX	Production costs	Sustainability	Operability	Flexibility and multifunctionality
Economic	x	x			
Sustainable			x		x
Security of supply				x	
Flexible					x

4.3 Designing the system

This paragraph covers the development of system design options based on the design philosophies described above up to the selection of the system design which will be subsequently serve as input for the system elaboration part.

4.3.1 Scenario definition

The four scenarios as described in paragraph 3.3.1 are defined for the Deventer case based on the four design philosophies from Table 4.7 Design philosophies. Table 4.8 gives an overview of the final scenarios: these are the scenarios that are developed after several iterations.

Table 4.8 Scenarios

Scenario	What's important	Location(s)	H_2 customers	H_2 demand profiles
Economic	CAPEX Production costs	S/Park	All potential customers	– AsfaltNu is limited to 15 % of total demand.[1] – Other potential customers are fully serviced
Sustainable	Sustainability Flexibility	AsfaltNu A1 fuel station Nefit Industrial	Van Dorp, Koninklijke Auping via production at the A1 fuel station. Other potential customers on-site	– AsfaltNu is limited to 76 % of the total demand – Other potential customers are fully serviced
Security of supply	Operability	S/Park A1 fuel station	AsfaltNu and Nefit industrial via production at S/Park. Van Dorp, Koninklijke Auping and fuel station via production at A1 fuel station	All customers are fully serviced
Flexible	Flexibility	S/Park A1 fuel station	AsfaltNu and Nefit industrial via production at S/Park. Van Dorp, Koninklijke Auping and A1 fuel station via production at fuel station.	All customers are fully serviced

The following things have been adjusted in the iterations to get to these scenarios:
- The amount of full load hours to get a feasible electrolyser capacity in the sustainable scenario.
- Peak shaving the demand of AsfaltNu to get a feasible result in the hydrogen utilisation decision tree in the economic and sustainable scenario.

4.3.2 System design development

Based on the scenarios, four system design options are developed. The table below gives a comprehensive overview of the system design options and is followed by a paragraph for each system design option containing its highlights.

[1] 15 % of the total energy demand is delivered in this scenario by limiting the capacity.

Table 4.9 System design options

Component	Economic	Sustainable	Security of supply	Flexible
Electrolyser/System integration	S/Park: 3 MW alkaline (8000 hours)	AsfaltNu and A1 fuel stations 3 MW PEM each (2000 hours) Nefit Industrial: 4 MW PEM (5000 hours)	S/Park: 5 MW PEM (5000 hours) A1 fuel station: 2 MW PEM (5000 hours)	S/Park: 5 MW PEM (5000 hours) A1 fuel station: 3 MW PEM (2000 hours)
H_2 demand	See Table 4.8	See Table 4.8	See Table 4.8	See Table 4.8
Hydrogen storage capacity	Small	AsfaltNu: Large A1 fuel station and Nefit Industrial: Small	S/Park: Large A1 fuel station: Small	S/Park: Large A1 fuel station: Small
Hydrogen transport method	Nefit Industrial via pipeline. Other customers by road.	Van Dorp and Koninklijke Auping to be determined. Other customer: on-site piping.	AsfaltNu and Nefit Industrial via pipeline. A1 fuel station: on-site piping. Van Dorp and Koninklijke Auping to be determined.	AsfaltNu and Nefit Industrial via pipeline. A1 fuel station: on-site piping. Van Dorp and Koninklijke Auping to be determined.
Electrical infrastructure requirement	Existing infrastructure is sufficient.	New infrastructure is required at all locations.	Existing infrastructure is sufficient at S/Park. New infrastructure is required at A1 fuel station.	Existing infrastructure is sufficient at S/Park. New infrastructure is required at A1 fuel station.
Electrical storage	No electrical storage	Determine the optimal setup in the next phase	No electrical storage	Determine the optimal setup in the next phase
Oxygen utilization	Oxygen utilization might be feasible for Nefit Industrial, evaluate in more detail.	Oxygen utilization at AsfaltNu and Nefit Industrial	Oxygen utilization might be feasible for Nefit Industrial and AsfaltNu, evaluate in more detail.	Oxygen utilization might be feasible for Nefit Industrial and AsfaltNu, evaluate in more detail.
Residual heat (radius for potential customers)	Up to ~1400 m	AsfaltNu: Up to ~500 m A1 fuel station: Up to ~500 m Nefit Industrial: Up to ~1700 m	S/Park: Up to ~2400 m A1 fuel station: Up to ~500 m	S/Park: Up to ~2400 m A1 fuel station: Up to ~500 m

If a hydrogen pipeline is constructed that serves both Van Dorp and Koninklijke Auping from the production facility at the A1 fuel station, the costs of transport by road are 60 % of the costs of a pipeline. With the level of detail in this phase this difference is not considered sufficiently significant to decide. Therefore, the transport method of hydrogen from the production facility to Van Dorp and Koninklijke Auping is to be determined. Because the road does seem a better option at this point, the costs for transport by road are considered in the evaluation of the system design options and this is also visualized in the next paragraphs.

Economic

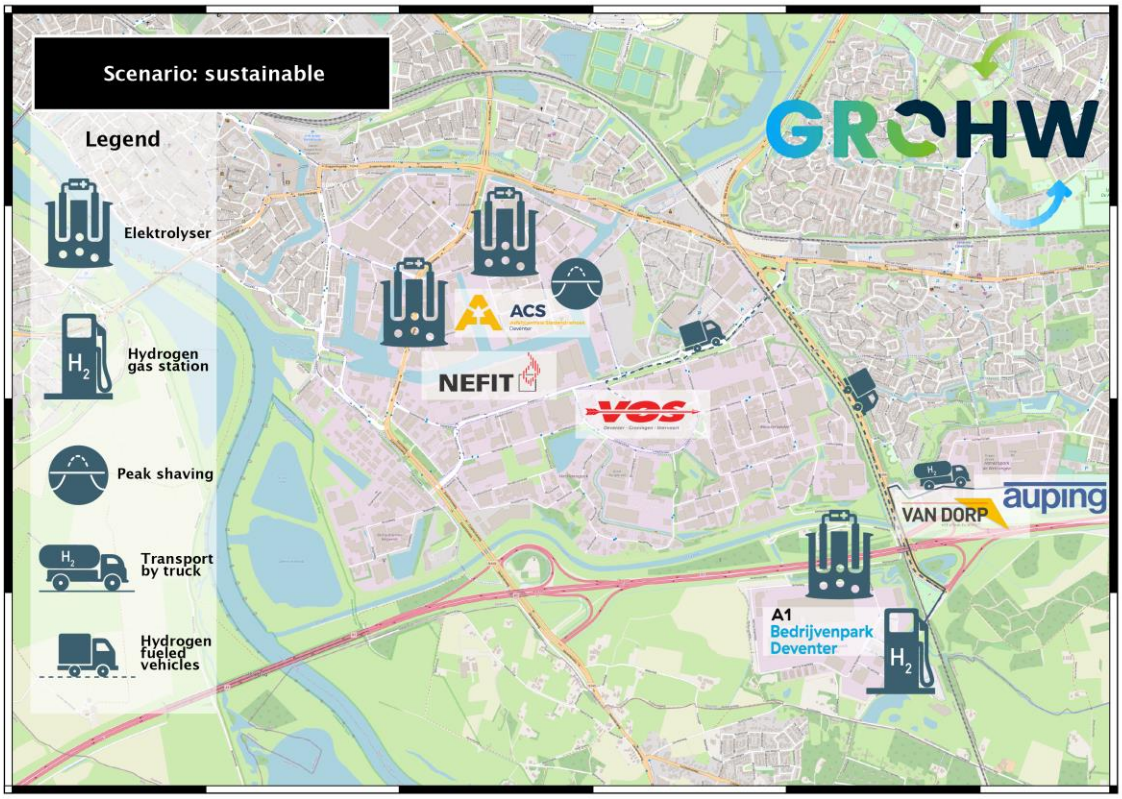
Figure 4.4 Economic design

Highlights:

- 3 MW alkaline electrolyser at S/Park
- Hydrogen pipeline to Nefit Industrial
- Transport by road to all other customers
- Only 15 % of hydrogen demand of AsfaltNu is delivered
- Oxygen utilization might be feasible for Nefit Industrial, evaluate in more detail

Sustainable

Figure 4.5 Sustainable design



Highlights:

- Decentral production:
  - 3 MW PEM electrolyser at A1 fuel station producing hydrogen for the fuel station, Auping and Van Dorp
  - 3 MW PEM electrolyser at AsfaltNu
  - 4 MW PEM electrolyser at Nefit Industrial
- 76 % of hydrogen demand of AsfaltNu is delivered
- Additional hydrogen storage at AsfaltNu required
- Oxygen is utilized at AsfaltNu and Nefit Industrial

Security of supply

Figure 4.6 Security of supply design

Highlights:

- Decentral production:
  - 5 MW PEM electrolyser at S/Park
  - 2 MW PEM electrolyser at A1 fuel station
- 100 % of hydrogen demand of AsfaltNu is delivered
- Additional hydrogen storage at S/Park required
- Hydrogen pipeline from S/Park to Nefit Industrial and AsfaltNu
- Transport of hydrogen by road or via pipeline from A1 fuel to Van Dorp and Koninklijke Auping
- Oxygen utilization might be feasible for Nefit Industrial and AsfaltNu, evaluate in more detail

Flexible

Figure 4.7 Flexible design

Highlights:
- Decentral production:
    - 5 MW PEM electrolyser at S/Park
    - 3 MW PEM electrolyser at A1 fuel station
- 100 % of hydrogen demand of AsfaltNu is delivered
- Additional hydrogen storage at S/Park required
- Hydrogen pipeline from S/Park to Nefit Industrial and AsfaltNu
- Transport of hydrogen by road or via pipeline from A1 fuel to Van Dorp and Koninklijke Auping
- Oxygen utilization might be feasible for Nefit Industrial and AsfaltNu, evaluate in more detail

4.3.3 Multiple-criteria decision analysis

Scaling the criteria

To compare the different criteria, each criterion is divided into scores of 1 to 5, 5 being the best score. The table below gives an overview of the evaluation matrix.

Table 4.10 Evaluation matrix

Criteria/Score	Very high (5)	High (4)	Medium (3)	Low (2)	Very low (1)
CAPEX	< 2 million EUR	2-5 million EUR	5-10 million EUR	10-25 million EUR	> 25 million EUR
Production costs	< 1 EUR/kg H_2	1-5 EUR/kg H_2	5-12 EUR/kg H_2	12-20 EUR/kg H_2	> 20 EUR/kg H_2
Sustainability	> 5 % more avoided CO_2 emission compared to average	1-5 % more avoided CO_2 emission compared to average	+/- 1 % around average avoided CO_2 emission	1-5 % less avoided CO_2 emission compared to average	> 5 % less avoided CO_2 emission compared to average
Operability	Very easy to operate	Easy to operate	Nothing specific	Complex to operate	Very complex to operate
Flexibility and multifunctionality	Both flexible and multifunctional	Flexible or multifunctional	Nothing specific	Inflexible or has only one function	Inflexible and has only one function

CAPEX and production costs are quantitative and can be determined using assumptions in the decision trees and additional assumption explained in the next paragraph.

Sustainability is assessed quantitatively by comparing the avoided CO_2-emissions of each system design option against the average avoided CO_2-emissions of all design options. The assumptions for the calculation are explained in the next paragraph.

Operability is more qualitative. It considers the complexity of the operations, from hydrogen production up to delivering it. The next paragraph discusses how each system design option has been judged on this criterion.

Finally, flexibility and multifunctionality are also more qualitative. A flexible design allows room for further changes in the system and a multifunctional design will also produce oxygen or alleviate grid congestion.

Scoring the system design options

The evaluation matrix is used to score all the system design options (Table 4.11). The scoring of each criterion is discussed in further detail in the following paragraphs.

Table 4.11 Unweighted score of system design option

System design option/Criteria	CAPEX	Production costs	Sustainability	Operability	Flexibility and multifunctionality
Economic	5 million EUR	3,28 EUR/kg H_2	-13 %	Complex	Inflexible and one function
Sustainable	19 million EUR	6,27 EUR/kg H_2	+1 %	Very complex	Flexible and multifunctional
Security of supply	15 million EUR	5,08 EUR/kg H_2	+6 %	Nothing specific	One function
Flexible	16 million EUR	5,27 EUR/kg H_2	+6 %	Easy	Flexible

Criterion 1: CAPEX

To calculate the CAPEX, the initial costs of the major components have been estimated. The major components included are:

– The electrolyser(s); For the CAPEX of the electrolyser, the following assumptions have been used:

- As a reference:
  - A 5 MW PEM electrolyser costs 1100 EUR/kW
  - A 2 MW alkaline electrolyser costs 962 EUR/kW
  - These prices are based on several quotes we have received from electrolyser manufacturers over the course of the project
- On top of this, 30 % is taken for balance of plant (compression, purification, and engineering)
- Based on this reference and expert judgement, 40 % of these total costs benefit from economies of scale with a scaling factor of 0,7[1]

– Additional costs for large hydrogen storage capacity; At this stage it is very hard to estimate the costs of hydrogen storage as the costs are highly dependent on pressure, capacity, and type of storage. Therefore, only additional costs in case of large storage capacities[2] are considered. These costs are assumed at 1 million EUR per location based on expert judgement.
– The hydrogen pipeline; 1 712 EUR/m for piping below sealed surfaces and 880 EUR/m for piping below greenfield[3]. These costs are discussed in more detail in the decision tree of hydrogen transport, appendix IV.
– Additional investment cost for having the production site at a new production location; Some locations could already have the required infrastructure (electrical, safety, permitting, organizational) in place for production of chemical gasses. S/Park is an example of that. Most location do not have this infrastructure in place though. We assume that an initial 1 million EUR investment is required to realise this infrastructure at new locations.

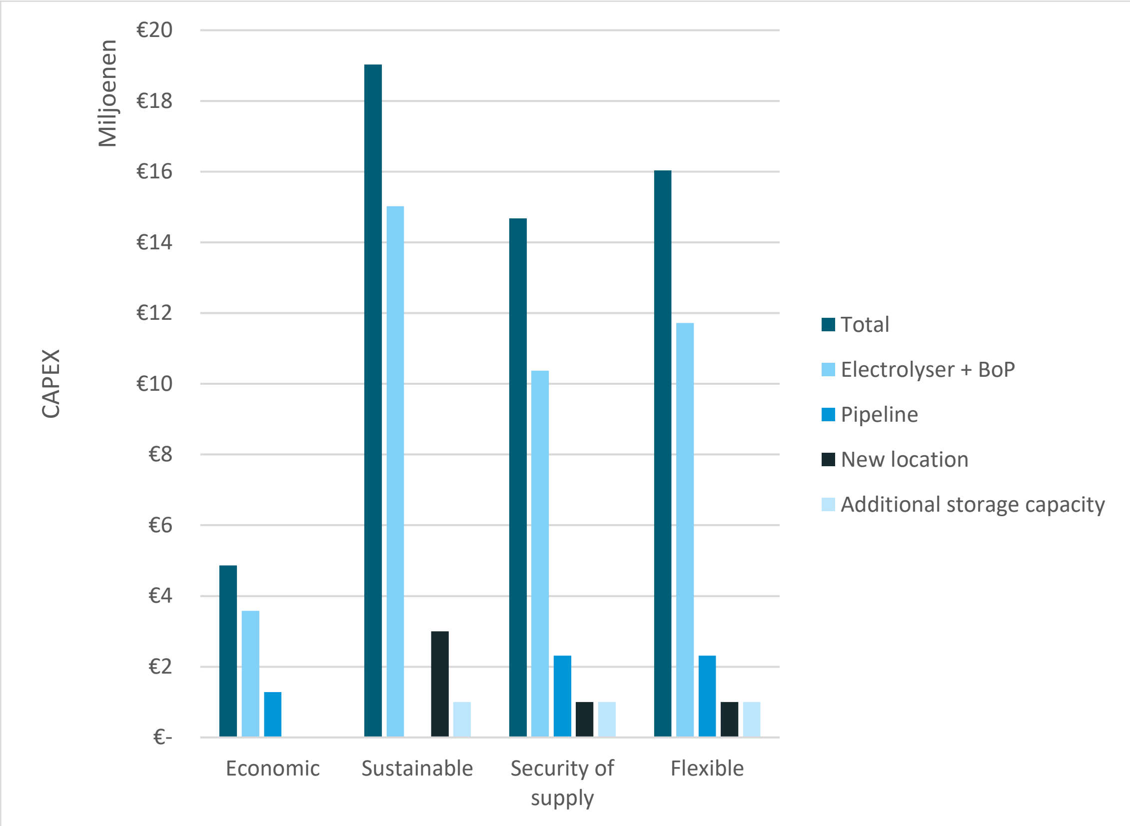
The figure below gives an overview of the CAPEX for each system design option. Clearly the sustainable design has the highest CAPEX, followed by the flexible and security of supply design. The economic design has the lowest CAPEX by far.

[1] i.e., a 2 MW alkaline electrolyser costs 2 501 200 EUR. A 4 MW (double the size) alkaline electrolyser then costs 2*60 %*2 501 200 + $2^{0.7}$*40 %*2 501 200 = 4 626 725 EUR

[2] The decision tree hydrogen utilization indicated whether small or large storage capacity is required.

[3] The total cost of ownership of the hydrogen pipeline is less than the CAPEX because it is assumed the pipeline can be sold after 10 years for 50 % of its value at that time. See appendix 4 for more details.

Figure 4.8 CAPEX per system design option



Criterion 2: Production costs

The production costs consist of the initial CAPEX plus the OPEX for 10 years expressed in EUR/kg H_2. Again, only the OPEX for the major components are considered. The OPEX are calculated for 10 years with a discount rate of 3 %. This consists of:

– Electricity for hydrogen production; For the costs of electricity, the following assumptions are used:
  - An electricity price of 44 EUR/MWh including green certificates. This price is based on the discussion during the plenary MCDA session.
  - An alkaline electrolyser is 80 % efficient, a PEM electrolyser 70 % in producing hydrogen.
  - 5 % additional power consumption is considered for compression and cooling.

– Subsidy; The production of green hydrogen is subsidised by the SDE++ subsidy (Rijksdiesnt voor Ondernemend Nederland, 2020). The subsidy is based on a varying prices per ton avoided CO2-emissions. Not all full load hours are subsidised because the power from the Dutch grid is mostly not sustainable. Therefore, the amount of full load hours that is subsidised is limited. The following assumptions are based on this subsidy and are a simplified version of how it actually works:
  - 150 EUR/ton avoided CO_2
  - A maximum of 2330 full load hours a year independent of the full load hours in of the design option

– Avoided CO_2 emissions are only based on avoided natural gas and diesel consumption assuming the same efficiency. This means, it is compared only on the energy content. The emissions of natural gas and diesel is based on the emission factors of RVO (Zijlema, 2020). Furthermore, this means that CO_2 emissions by the hydrogen hub are neglected.

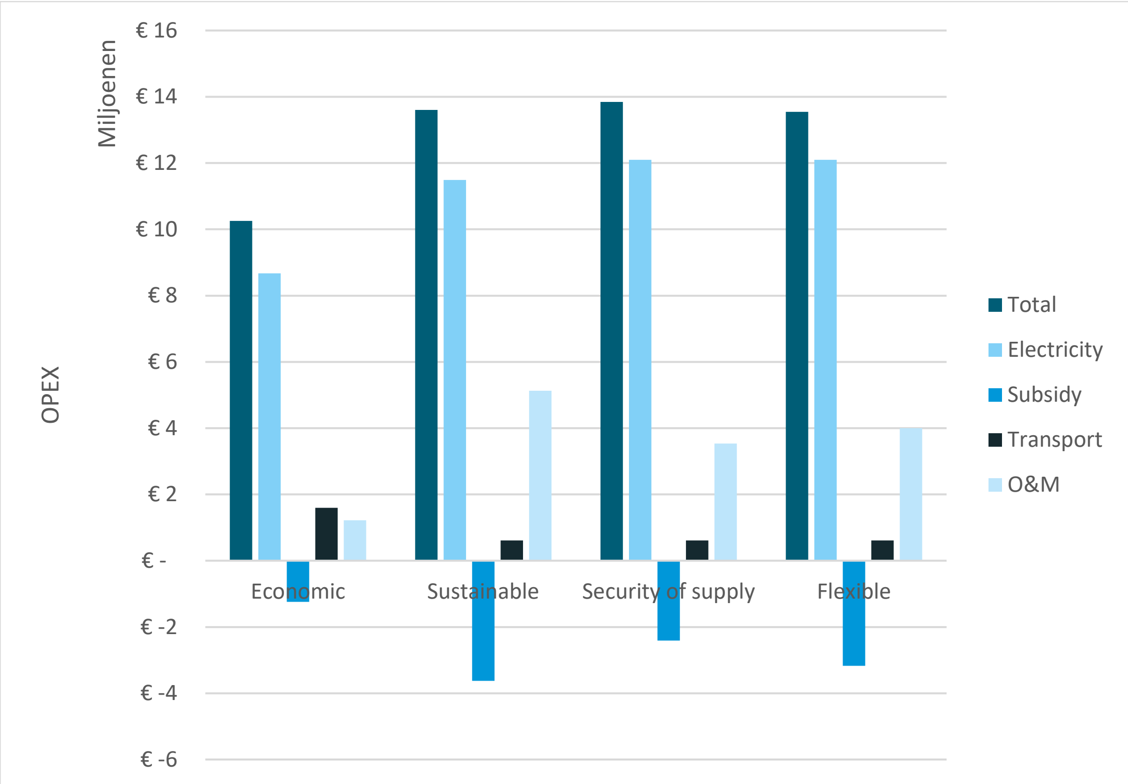
– Transport by road; This is 13 480 EUR/ton hydrogen for 10 years. This is based on the following assumptions:
  - One delivery of hydrogen is 200 kg, regardless of pressure
  - One delivery takes three hours, including loading, unloading, travel to and from the starting point of the truck, and travel between the production and drop-off location

- The total travel distance is 150 km per delivery, regardless of the distance between the production and demand location. We assume that the distances within the hydrogen hub are negligible with respect to this distance.
- The cost for the driver is EUR 35 per hour
- The cost of the truck is EUR 50 per hour
- The truck uses 30 L of diesel per 100 km
- Diesel costs EUR 1,356 per L

– Operation and maintenance (O&M) per year is assumed at 4 % of the Electrolyzer + BoP CAPEX based on expert judgement.

The figure below gives an overview of the production costs for each system design option. All design options have similar OPEX except the economic option, which is significantly lower. However, the economic scenario also produces the least hydrogen, followed by the sustainable scenario. This results in low production costs for the economic and security of supply design and medium production costs for the flexible and sustainable design as shown in Table 4.11.

Figure 4.9 OPEX for 10 years per system design option



Criterion 3: Sustainability

The avoided CO_2-emissions are based on the same assumptions that are used in the subsidy calculation described in the previous paragraph. Because the avoided CO_2-emissions are determined based on the avoided natural gas and diesel consumption the security of supply and flexible design score the highest on this criterion followed by the sustainable design and finally the economic design.

Criterion 4: Operability

Operability is qualitative. The reasoning for each score is as follows:

– The **economic** option is considered complex because the system is based on 8000 full load hours and has an alkaline electrolyser. This makes the production facility little flexibility in production which makes it complex to match supply and demand of hydrogen.

- The **sustainable** option is considered very complex because it is based on following renewable energy production. Therefore, the supply of hydrogen demand will even be harder to match with the demand. Furthermore, it comprises three production locations.
- The **security of supply** option has nothing specific. It is considered an ordinary production facility from this perspective and therefore scores medium.
- The **flexible** option has an electrolyser at the A1 fuel station that has three times the capacity compared to the security of supply option while the total hydrogen demands remains the same. Therefore less full load hours are required which makes it easier to match supply and demand. Therefore this option is easy to operate.

Criterion 5: Flexibility and multifunctionality

Flexibility and multifunctionality is qualitative as well. The reasoning for each score is as follows:
- The **economic** option is considered inflexible because it requires almost non-stop operation to meet the hydrogen demand. Therefore, it is almost impossible to increase its capacity for future customers without redesigning the complete system. Furthermore, it only serves one purpose: producing hydrogen.
- The **sustainable** option is considered both flexible and multifunctional. Flexible because the large capacities of the electrolysers allow for little full load hours to meet the current demand. This makes it easier to expand in de future. Furthermore, this flexibility also allows to alleviate grid congestion and the produced oxygen is utilized.
- The **security of supply** option is geared towards only one function: producing hydrogen. There is nothing specific from the perspective of flexibility.
- The **flexible** option is considered to be flexible (obviously) because the capacity of the electrolyser at the A1 fuel station is over-sized and the design should allow for future oxygen utilization. The design does however serve only one purpose still: Producing hydrogen.

Weighing the scores

The results from Table 4.11 are now multiplied with the weights of Table 4.6 to give each system design option a single weighed score of 0 to 5 and rank them based on this score. Table 4.12 ranks the system design options based on the total score and shows how each criterion contributes to the total score. The system design options are ranked from high to low based on the total score.

Table 4.12 Weighted score of the MCDA.

System design option	Total score (Rank)	CAPEX	Production costs	Sustainability	Operability	Flexibility and multifunctionality
Flexible	3,61 (1st)	0,28	0,81	0,80	1,08	0,64
Security of supply	3,02 (2nd)	0,28	0,81	0,80	0,81	0,32
Sustainable	2,64 (3rd)	0,28	0,81	0,48	0,27	0,80
Economic	2,36 (4th)	0,42	1,08	0,16	0,54	0,16

From Table 4.12 it is concluded that the flexible (4,0) system design option is most favourable, followed by security of supply (3,6), sustainable (2,9) and economic (2,4). In Paragraph 4.3.4 these results are discussed in more detail.

4.3.4 Discussion

The results in the Table 4.12 serve as a starting point for a qualitative discussion. The minutes of meeting of this discussion can be found in appendix VI. An overview of the most important points:
- At this moment the user profiles of the various users are seen as a fact. However, these users have not given a commitment to indeed take off this amount of hydrogen. This commitment depends for example

on feasibility and price (€/kg) of the hydrogen. Therefore, it could well mean that much lower capacity of the electrolysers is needed, especially on the short term. In the system elaboration phase a smart strategy should be applied to grow the system in small and manageable steps.

- Some of the partners within the GROHW project are designated as end-users, but in the case of hydrogen for mobility, these are not the real end-user. The real end-user is a hydrogen fuel station owner, which is not a partner. As a hydrogen fuel station owner is essential for commitment (see previous comment) this may be an essential partner.
- The consortium does not comprise of an operator of the final realised design. This operator may be the most essential party for the commitment and have the highest say in the decision of the design. Therefore also an operator may be an essential partner.
- The security of supply and flexible system design option only differ in the installed capacity at the A1 fuel station. 2 MW in case of security of supply and 3 MW in the flexible option. This also translates in a very similar evaluation of the scores. Therefore, the final decision is made to go for a hybrid of these two options: Construct a 2 MW electrolyser at the A1 fuel station but design it in a such a way that is easy to extend to 3 MW. For the electrolyser at S/Park a similar approach may be taken: start with 1 MW and gradually increase. This also addresses the uncertainty addresses above.
- The MCDA also does not show beneficial effect from the utilization of oxygen. The sustainable option would benefit the most from this, followed by the flexible and security of supply option. As the decision tree indicates, further evaluation of oxygen utilization in the security of supply and flexible option is required. We have evaluated these cases in further detail and concluded that oxygen utilization is feasible for Nefit Industrial and AsfaltNu. Because we aim for one modular design, the electrolyser at the A1 business park will also be built for oxygen. However, oxygen treatment facilities will not be realised at this location.
- Transporting hydrogen by road does not seem a very sustainable option because it requires trucks which normally run-on diesel. It is therefore important to keep sustainability in mind when deciding about transporting hydrogen by road. Trucks could be fuelled by hydrogen for example, or it could be worth the extra investment to construct a pipeline.
- The sustainable option doesn't have the highest score on the sustainable criterion. This is because the avoided CO_2-emissions are determined based on the avoided natural gas and diesel consumption. In the sustainable design options, only part of the H_2-demand is delivered to AsfaltNu and therefore less natural gas is replaced. This system design option does have the highest score on flexibility and multifunctionality.
- It is assumed that the lifetime of the stacks is sufficient to operate for 10 years with the specified amount of full load hours. This assumption however is not considered valid by everyone in the group. It was suggested that the lifetime may be lower than 10 years. As this value is not giving a distinguishable outcome between the different design options, it was not further elaborated on. It is, however, good to keep this in mind when making the final investment decision.
- The MCDA does not show the beneficial effects from alleviating grid congestion and supplying grid balancing services to system operators sufficiently. The sustainable option would benefit the most from this, followed by the flexible and security of supply option. This will be further elaborated on in the system elaboration part as part of the business case and financing analysis work package.
- In the end, the price of hydrogen is considered the most important criterion by the group. If the hydrogen is too expensive it is just not competitive, and the project will not be feasible. However, if only costs would be considered an MCDA would not have been necessary. Furthermore, as Table 4.6 shows, other criteria are considered important as well. Therefore, the following system design options are ruled out:
    - Economic, because it only scores well on cash and production costs
    - Sustainability because it is too expensive

4.3.5 Conclusions

The in the MCDA selected system design is a hybrid between the security of supply and the flexible option. This hybrid system design comprises two production locations: S/Park and the business park A1 Table 4.13

describes this system in more detail and this table can be used as starting point for the electrolyser design, system integration, trading platform and business case and financeability analysis.

Table 4.13 System design hybrid option for Deventer

Component	S/Park	A1 fuel station
Electrolyser	5 MW PEM (based on 5000 full load hours)	2 MW PEM (based on 5000 full load hours) with the ability to extend to 3 MW
H_2 demand	AsfaltNu and Nefit industrial	A1 fuel station, Van Dorp and Koninklijke Auping
Hydrogen storage capacity	Large	Small
Hydrogen transport method	Pipeline	A1 fuel station: on-site piping Van Dorp and Koninklijke Auping to be determined
Electrical infrastructure requirement	Existing infrastructure is sufficient	New infrastructure is required
Electrical storage	Determine the optimal setup in the next phase	Determine the optimal setup in the next phase
Oxygen utilization	Including oxygen utilization for Nefit Industrial and AsfaltNu	Only the electrolysers are compatible for oxygen utilization, no further facilities are included
Residual heat (radius for potential customers)	Up to ~2,4 km	Up to ~0,5 km

4.3.6 Recommendations

Consider the following in the system elaboration part of the project:
- Critically evaluate the expected hydrogen demand profiles for each customer
- Critically evaluate the utilization potential of hydrogen for the different customers
- Critically evaluate the assumptions used for the efficiency and lifetime of the stacks
- Determine the optimal storage pressure
- Consider both transport options for hydrogen from the electrolyser at the A1 fuel station to Van Dorp and Koninklijke Auping
- Determine the possibilities (need and size) for electrical storage
- Review the decision trees based on the discussions/gained insights during the MCDA
- Include alleviating grid congestion and supplying grid balancing services in the business case analysis
- Consider starting with two electrolysers of 1 MW at each location and in time increase the installed power
- Consider if the right partners are present in the consortium.

4.4 Electrolyser design

For this GROHW project MTSA has developed a 1 and 2 MW PEM electrolyser design. The starting point of the design (Appendix VII) is that the electrical power arrives from a green source like wind and sun (PV). Therefore, the electrical input is fluctuating. The unit is modular designed, so it is easy to change, or to add other components and it is ready for future larger capacities (limited).

4.4.1 Basis of Design

The Basis of Design (BoD) is carried out by MTSA, and consists of the following technical documentation:
- System specifications; (Appendix VIII)

- PFD; (Appendix IX)
- Mass Balance (Appendix X)
- Layout (Figure 4.10)

Figure 4.10: Schematic representation of two 1 MW elektrolysers including cooling tower (grey top area)

4.4.2 Process description

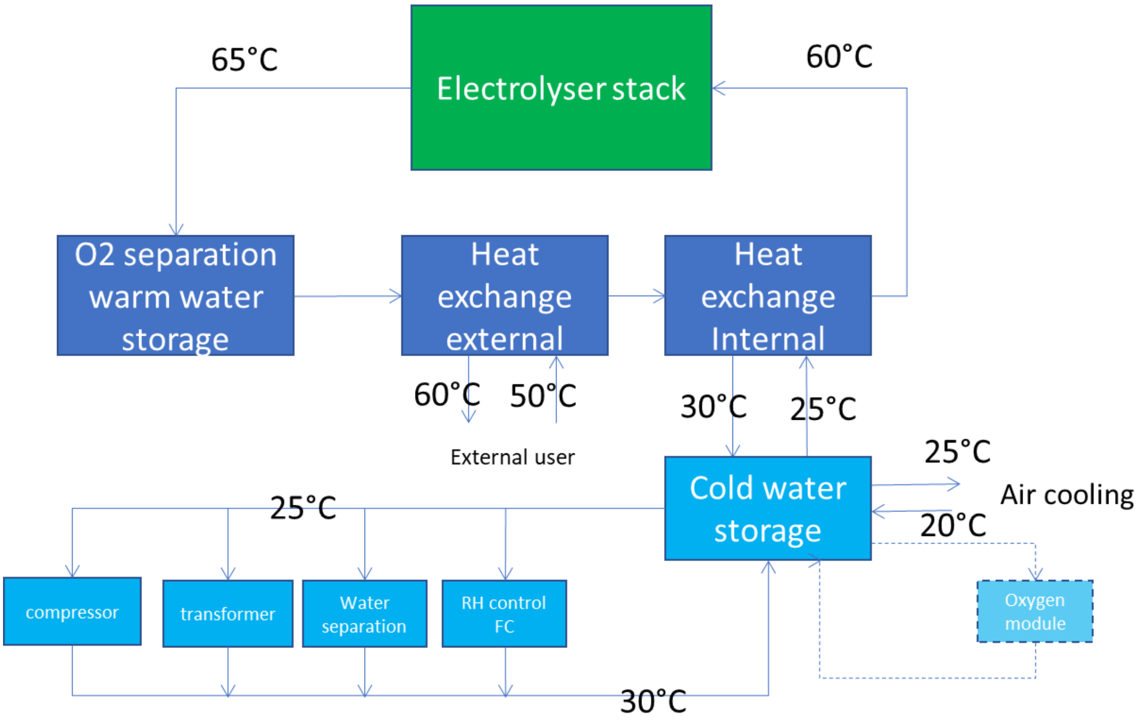
Potable water is treated to produce purified/pure water. Pure water is split in an electrolysis stack using the electrical power into hydrogen. This hydrogen can be utilised by different users. The electrolyser is also producing oxygen and heat, which can be used by various nearby users if needed. The design allows for switching the utilisation of oxygen 'on' or 'off' depending on the costumers' preferences. The design contains two cooling cycles (Figure 4.11):

- The pure water with a temp of 60 - 65 ^{0}C
- A cooling cycle with water glycol with a temp of 20 - 30 ^{0}C

The design includes the following components:

- Water purification unit
- Oxygen/water separation
- Hydrogen/water separation
- Cooling
- Hydrogen purification
- Transformer / Rectifier
- Electrolyser stacks

Figure 4.11 Scheme of the two temperature cycles in an electrolyser



The following assumptions are used for designing the electrolyser:

- A compact unit with an electrolysis stack splitting water using electrical power into hydrogen and oxygen.
- The electrolysis stack is based on the PEM (proton exchange membrane) technology because of flexibility regarding the frequent starting and stopping (due to renewable energy) and the compactness of the stack.
- The electrolyser is suitable for connection with the flexible output coming. In principle the input power is designed to be between 10 % and max power (= 1 or 2 MW), but this must be verified by experiments.
- The power source is coupled to a 10 KV AC power grid, mostly the PV and wind parks are also coupled to this medium voltage grid.
- The hydrogen is produced with the max possible pressure (= 40 barg). This reduces possible oxygen contamination and reduces costs for further compression steps.
- When the electrolyser stops, a short nitrogen flush removes the hydrogen and oxygen out of the stack, avoiding fuel cell activity. This also increases the lifetime of the stack.
- The quality of the hydrogen is monitored, the system stops when the quality is lower than the specification.
- The quality of oxygen is monitored: especially when the hydrogen level in oxygen is too high the whole systems stops.
- The water level can be reduced depending on the supplier/needed quality.
- The electrolyser needs a temperature between 60 and 65 ^{0}C. This will be arranged by a continues flow of warm pure water. This water is used partly for cooling and partly for splitting the water into hydrogen and oxygen. The heat created by the electrolyser is standard cooled away, using a cooler on the roof of the electrolyser. In principle this heat can be used for third parties using an extra heat exchanger, but temperature will be not higher than 55 ^{0}C and is related to the running period of the stack.
- The cycled pure water will be partly refilled by a pure water production installation and will be monitored through a conductivity measurement.
- The electrolyser needs pure water, this is performed in the water treatment unit. The pure water unit is divided in softening, reversed osmosis, EDI (electro deionization) and absorption. In principle this unit can produce pure water for third parties when the electrolyser unit is not working.

- The electrolyser is producing humid oxygen (saturated), in standard configuration this will be emitted to the atmosphere. In principle this can be used by third parties. The unit is fully automated with remote control.
- The unit can be connected with a system for trade with electricity and/or hydrogen.
- The unit will fulfil the highest safety standards.
- By using Swagelok Tube fittings and when possible welded connections leakage will be reduced.
- Hydrogen and oxygen levels are monitored and will shut the system when an unsafe situation is formed.
- All equipment is grounded.
- Electrical connections and/or other possible charge critical units/equipment will be placed as low as possible (hydrogen will be always on the top). When needed Atex components will be used.
- The unit can be expanded with a hydrogen compressor, hydrogen fill station, natural gas mixing station, hydrogen storage, oxygen dryer, oxygen storage, oxygen compressor, ozone generator.
- All components are placed in containers. These containers can be locked, they are well vented and heated in winter conditions.

Input elektrolyser

Electrical Power

For 1 MW elektrolyser design 6-7 % is used for the BoP. The rest is converted by a transformer/rectifier with an efficiency of 95 % to the electrolyser stack. The remaining 0,89 MW is used for the electrolysis process. With a theoretical efficiency of 85 % water is split into hydrogen and water. In practice the efficiency is lower and is depending on the current density (becomes lower with higher current density), temperature (higher temp gives higher efficiency, but will reduce lifetime and voltage). During the lifetime the voltage will increase giving a higher current density creating a lower efficiency in time.

Potable water

For the below max. production of hydrogen, oxygen, and waste heat: an inlet of 232 kg/h tap water is needed. The treatment towards pure water gives a small drain with a higher concentration salt than normally already present in tap water. Continues drain to surrounding: approx. 70 L/h for 1 MW and 140 L/h for 2 MW (depending on the quality of the tap water).

Output elektrolyser

The following products are produced within the electrolyser installation (see Appendix VIII for more specifications):

Hydrogen

Pressure: max. 40 bar(g)
Temperature: 20 °C
For 1 MW: max 17,8 kg/h, min is 10 % of max (must be tested). For 2 MW this is doubled.
The water content is depending on the requirements of the client; without treatment is 0,95 kg/h (based on a 17.8 kg/h H_2 output), with a cooling unit this is reduced to 0,95 kg/h. When using a purifier this can be reduced to 0,008 kg/h
Storage pressure: 40 bar

Different end users at one location may require different qualities of hydrogen. Our design has one quality: the PEM stack gives apart from water nearly 100 % purity. The high output pressure of hydrogen prevents contamination of oxygen. For mobility and/or further compression an extra drying step is required.

Oxygen

Pressure: max. 6 bar(g)
Temperature: 20 °C
Water content: saturated
For 1 MW: max 141 kg/h O_2 (based on dry gas), min is 5-10 % of max (must be tested). For 2 MW this is doubled

The treatment of oxygen (e.g. drying) is not part of MTSA's scope and is therefore not considered in this chapter. Oxygen treatment is discussed in Chapter 3.5. It is assumed that the oxygen is utilised as well, but in case that the oxygen is not utilised, it can be vented to the atmosphere (flexible design).

Heat
The unit also produces heat. The max. usable temperature is 55°C.
The total max. usable heat for a 1 MW is 360 kW, only available when the electrolyser is running on max power.

4.4.3 Design principles

The BoP of the electrolyser is designed to deliver high quality water to the electrolysis stack and processes the produced hydrogen and oxygen in a save and highly efficient method with the highest possible quality. The elektrolyser design includes at least:
- Electrolysis stacks; (in principle 1 for 1 MW and 2 for 2 MW, but it is also possible using smaller units)
- Equipment for filtering and treating of drinking water to ultrapure water (UPW)
- Equipment for circulating and cooling UPW over the stacks and separating UPW and oxygen
- Equipment for treating UPW which is circulated over the stacks, to remove impurities
- Equipment for removing hydrogen from the stacks and treating it for its different purposes
- Low pressure buffer vessel for hydrogen
- Compressor(s) for compressing hydrogen to a certain pressure
- High pressure storage for hydrogen
- Equipment for cooling UPW from a relatively high to a slightly lower temperature see fig 4.2.
- Equipment for cooling back cooling water from a relatively medium to low temperature and supplying this to several applications within the electrolyser (cooling cycle 2)
- Equipment for transforming and rectifying the supplied electrical power to make it suitable for application in an electrolysis stack
- Various vessels, including amongst others supply vessels and process vessels (e.g. gas-liquid separators)
- Equipment (e.g. pumps, heat exchangers, filters)
- Piping, filters, (control) valves, etc. to connect all equipment
- Instrumentation to monitor and control the process and make sure that it operates in a safe manner
- Control system for the installation as described in this document, which can communicate with the overall control system on site

The following utilities are required:
- Electricity, for generating hydrogen and running the system
- Instrument air / compressed air, to operate pneumatically actuated valves
- Nitrogen, for purging the system
- Drinking water, for making UPW
- Cooling water, to cool UPW, oxygen and hydrogen
- Drain(s), for releasing by-products

The following is not part of the scope:
- Equipment for any further treatment of oxygen
- Equipment for supplying hydrogen to a hydrogen fuel station
- Piping to transport the various gasses to the end user(s)
- Equipment for cooling back the heated cooling water from cooling cycle 1 (as this can possibly be used for other applications that require heat)
- Supply of utilities
- Back-up power supply in case of a power failure
- Battery package for temporary storage of electrical power in case this turns out to be required

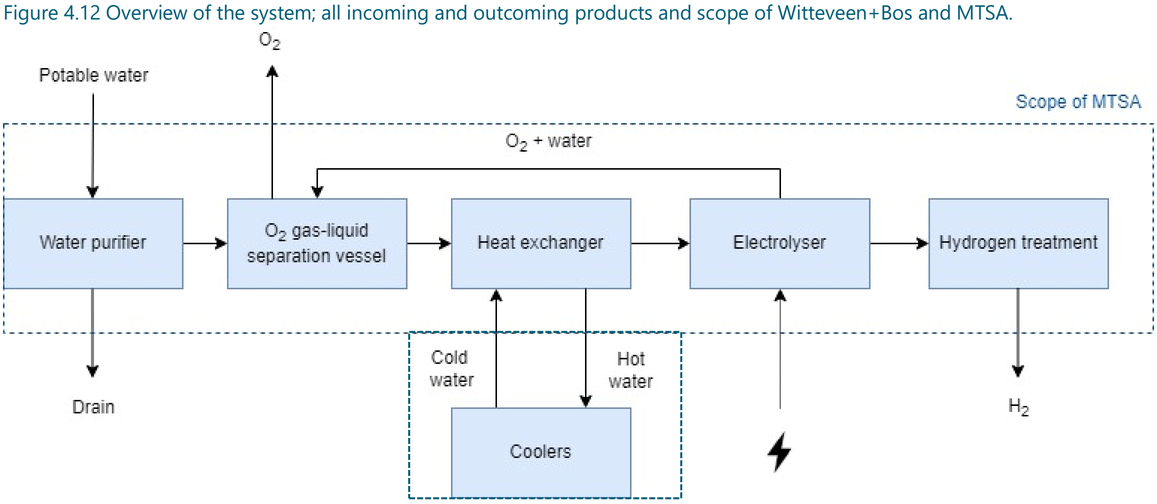
4.4.4 Conclusions

With this MTSA equipment design, it is possible to use renewable green electricity and pure water and change it in another energy source (hydrogen) what can be stored and used when needed. Apart from hydrogen the unit is also producing oxygen and waste heat what can be used as extra products, improving the business case of the electrolyser. Based on this design a blueprint for a 1 and 2 MW electrolyser is designed, based on the set-up/system building blocks, but the lay-out for each power is different and needs custom engineering. The building blocks can increase flexibility and repetition. There may be a potential to also increase the capacity if bigger building blocks (higher MW) are used, but this was out of the scope of this project.

4.5 System integration

The system integration part of the project covers the interface between the electrolyser system (scope MTSA) and the site location (Figure 4.12) and is expressed as the Basis of Design (BoD) (Appendix XI). The electrolyser was planned to be located at the A1 Business Park in Deventer, but this was not confirmed yet. For this reason, the BoD is made independently of the location, so that it functions as a basis not only for the currently selected A1 business park location, but for other hydrogen electrolyzer projects in the future as well (blueprint thought). The electrolyser's main goal is to use the energy surplus at peak hours. It consists of two 1-MW electrolysers, so its nominal power is 2 MW. The electricity is supplied by the grid. The systems runs 5000 fuel load hours annually which corresponds to the requirements of the subsidy of SDE++ and falls in the main category 'CO_2-arme productie' (CO_2 lean production) and the subcategory 'Waterstof door elektrolyse' (Hydrogen through Electrolysis). The electrolyser requires electrical energy, potable water, and cooling. The products produced (the hydrogen, oxygen, waste heat and wastewater) need to be distributed and/or drained off correctly.

Figure 4.12 Overview of the system; all incoming and outcoming products and scope of Witteveen+Bos and MTSA.



4.5.1 Basis of Design

A Basis of Design is composed for facilitating the system integration. This Basis of Design is composed by following the approach visualised in Figure 4.13. The Basis of Design is included in Appendix XI.

Figure 4.13: Schematic approach Basis of Design

Gather input data and requirements

Firstly, all input data was gathered or estimated in case no data was available. Most data needed for the system integration concerned the electrolyser system and was therefore obtained from MTSA. Besides this, information about the location was required. As described before, the initially intended location for the hydrogen hub, S/Park, turned out to be less favourable later on in the project. Therefore, it was decided to assume that the hub would be placed at the A1 Business park. This location switch means that the system will be connected to a different grid operator (Liander instead of Enexis) at a different mid voltage substation. The location is also farther away from the hydrogen consumers, meaning that a pipeline to supply the consumers directly with hydrogen was not a viable option anymore and the hydrogen will be distributed by or to the consumers by road transport. The safety requirements and regulations as described in Section 3.2.3 apply to the system integration design as well.

Determine process and design conditions

Based on the gathered information about the electrolyser system, the location and the safety requirements and regulations, the process and design conditions were determined, as can be found in Appendix XI.

Select system integration equipment

After determining the Basis of Design, all equipment required for the system integration was selected and added to the equipment list of the whole project. The equipment list can be found in Appendix XII.
The system consists of the container(s) for the elektrolyser and a container for the oxygen treatments system. The electrolyser will be fed with electrical energy and potable water. The electrical energy will be supplied by a 10 kV cable from the grid (Liander), which will be connected to the transformer in the electrolyser system. The potable water will be fed by a water pipeline from the local water supplier (Vitens) to the water purifying system in the electrolyser container. The dried hydrogen coming from the electrolyser system will be compressed by a compressor from 40 barg to 200 barg. This pressure is suitable for storage in both tubes and cylinders, depending on what the consumer requests. The oxygen coming from the electrolyser will be dried in the oxygen treatment container and compressed to 200 bar(g), which is the industrial standard pressure. Both the oxygen treatment system and the hydrogen compressor will be fed by the electrical energy supply from the low voltage side of the transformer in the electrolyser system. Produced wastewater will be connected to the sewage system. Cooling can be done by either adding a cooling system in the electrolyser system or tapping the residual heat and using it for heat purposes elsewhere. For example, the residual heat coming from the system can be used for district heating if heat demand is present nearby. However, this was not assumed in the Deventer scenario. Therefore, the electrolyser system was cooled using internal cooling.

4.5.2 Conclusions

The electrolyser system can be integrated into the location by connecting it to the local grid using a 10 kV cable, the local water supplier Vitens and the local water sewage system. Most of the processing steps that need to be done on both the inlet and outlet of the electrolyser is already integrated in the electrolyser system designed by MTSA, except for the hydrogen treatment and oxygen compression. Both systems are commonly used equipment in the industry and can be considered proven technologies. Based on the consumer's demand, the output pressure, hydrogen quality and other characteristics of the oxygen and hydrogen can be determined. These characteristics are essential for the design of the system integration system. In future projects, it is recommended to get these characteristics clear as soon as possible. To achieve this, it is very important to include the consumers early in the project process.

4.6 Trading platform

The development of the trading platform is based on the *flexible system design* of the Deventer case (Paragraph Designing the system 4.3):
- 5 MW electrolyser at S/Park for AsfaltNu and Nefit Industrial
- 3 MW electrolyser at A1 fuel station for Van Dorp, Koninklijke Auping and A1 fuel station
- Renewable energy (electricity) generated by:
  - Two wind turbines next to A1
  - Two solar farms: Wilp (117.416 panels) and Heijmans A1 (6746 panels)

The answers to the questions (Q&A) and simulations mentioned in paragraph 3.6.2 resulted in a list of functional requirements and recommendations for the trading-system (Appendices XIII, XIV, and XV). Below a selection of notable insights from the Q&A and simulations is given:
- Electrolysers must be kept running at all times. Renewable energy sources alone are not stable enough to provide a constant flow of energy for the electrolysers. Therefore, a fallback to energy from the grid is required. In order the keep the energy green, certificates must be obtained.
- Customers are only interested in hydrogen if it is green.
- Electricity shortages and – surplus can be traded through a Balance Responsible Pary (BRP). In addition, this party can facilitate trading in green certificates.
- Dynamic prices result in a lower self-consumption rate (the amount of hydrogen that is produced by energy from the renewable energy sources). This is caused by the possibility to trade the fluctuations of the EPEX SPOT price and the low price of a European GoO.
  - However, dynamic electricity prices are determined to have a 7.19 % average cost reduction on the fuel cost for hydrogen compared to a system with only storage.

Based on the requirements and recommendations, an overview of the information architecture was created (Appendix XV). This helped identifying the required actors, sensors, and external data-sources.

4.6.1 Description of the Minimum viable product

The realization of a Minimum Viable Product (a basic version of the trading platform) consisted of the actual development of the agent-software with accompanying hardware and the software for the overall trading platform in which the agents operate. Appendix XVI gives a schematic of the trade-steps and screenshots of the local and global dashboards of the MVP.

The agent-software runs on a piece of hardware called the HanzeBox. The HanzeBox connects with a smart-meter (for measuring electricity consumption/production), an electrolyser and any other energy-related device. The agent-software is accessible by the user through a web-application. This application visualises the measured energy-values and the traded energy of the client.

The trade logic - which tailors the marketplace to the specific use case – is added ‘on top’ of the platform, meaning that modifications and improvements can easily be implemented. The trade logic for this MVP is preference-based. Users can modify their trade-preferences, which are used by the agent-software to formulate trade-requests at a defined interval. Configurable preferences are:
- Buy solely from local energy producers
- Buy from local storage
- Buy from the grid
- Buy from solar energy
- Buy from wind-energy
- Buy from energy-sources nearby

The trading platform enables the trade of multiple energy-types (e.g. electricity, hydrogen, heath). Trading of energy happens in defined intervals. It consists of multiple steps:

1 An agent registers local production, consumption, storage, and conversions and publishes it to the network of the trading platform.
2 Other agents receive this information, which they can use to formulate a trade-request (e.g. buy x amount of energy y from agent z).
3 Trade-requests are then published and processed by the network. A global dashboard visualizes every transaction, accompanied with statistics per energy source and -type.

4.6.2 Testing

Testing was performed through simulations and an actual field-test consisting of 50 households, a solar park, and the electricity-grid. The test did not involve dynamic prizing; therefore the decision-making was simplified to focus on the decentralized architecture. Also, the test was done administratively. There was no communication with the grid-operator or any energy-provider. During the test, many improvements were developed and implemented along the way. Insights from the test:

- **Performance**: the trading platform supports at least 50 participants, and it is expected that this number will be a lot higher since the computing power is distributed due to the decentralized nature.
- **Trade-preferences**: Trade-preferences are only applied for buying energy. Sell-preferences could add a new dimension to the trade system.

Improvements will be explored and piloted in GROHW phase 2 at *De Gasfabriek* in Deventer. For this next pilot, the MVP will be applied for trading electricity, hydrogen, and waste-heath; the clients consist of solar panels, an electrolyser, a hydrogen-based heating system and a universal station for buying hydrogen.

4.6.3 Conclusions

We developed a first MVP to test the proposed *decentralize multi-energy trading platform* in the field. This MVP needs the following adjustments to be applicable to phase 2:

- Connect with an electrolyser
- Add hydrogen and waste-heath as energy-type
- Improve decentralized decision-making, by implementing dynamic pricing and sell-preferences
- Explore the parameters that should be configurable by the participants (e.g. trade-preferences, -limits, etc.) and determine the interface

To function as a blueprint for new projects we envision, a system similar to the *flexible system design* should be used as a starting point. The research questions need to be answered to determine the exact requirements of the system. For a similar system, many insights are reusable (such a regulatory aspects).

Furthermore, simulations can be performed to determine whether dynamic pricing is useful in the specific case and to determine the role of external energy sources on the trading platform.

4.7 Business case and financeability analysis

This paragraph discusses the business case and financeability analysis for the 2 MW electrolyser system at the A1 business park. Input parameters are 5000 full load hours leading to a total of 12.195 MWh electricity consumption, producing 190.000 kg of hydrogen and 1.420.000 kg of oxygen. No transportation/delivery costs for the hydrogen and oxygen are used as the sales prices include the pickup these gases by Westfalen.

4.7.1 Business case

Table 4.14 summarizes the business case input parameters. Hydrogen and oxygen prices were quoted by Westfalen, based on offtake in 50 litre cylinders at 200 bars. Such a cylinder contains 0,9 kg hydrogen and the offtake price range is 9-12 EUR. The lower end of the range was used and an annual decrease in price of 2 % is assumed due to increasing hydrogen production capacity. For replacement of the stacks after 40.000 full-load hours (Chapter 3.4), ~year 9, there is an estimated price development of -26 %.

Table 4.14 Other business case inputs

Parameters	Value	Unit	Source
Capacity electrolyser	2	MW	BoD
Depreciation	16	year	W+B
Lifetime stacks	40.000	full-load hours	MTSA
Full-load hours	5.000	hour/year	BoD
Cost development of stacks replacement in year 9	-26 %	-	MTSA
SDE++ subsidy	50 %	% of maximum tariff	W+B
Electricity price	34	EUR/MWh	PBL
Sales price H_2	10	EUR/kg	Westfalen
Sales price O_2	0,07	EUR/kg	Westfalen
H_2 production	19	kg H_2/MWh	BoD
O_2 production	142	kg H_2/MWh	BoD
Price development H_2, O_2	-2 %	annual change	W+B
Price development OPEX	+2 %	annual change	W+B
Discount rate	3 %	-	W+B

Table 4.15 summarizes the CAPEX for the project, based on the BoD (Appendix XI), quotes from suppliers (MTSA and non-consortium parties) and cost estimates by Witteveen+Bos experts on civil works and permits. The total investment costs are EUR ~7.5 million, of which 84 % is made up by the electrolyser and balance of plant components. The filling station costs were quoted by Westfalen and consider a filling station for 50 litre cylinders at 200 bar.

Table 4.15 CAPEX

Components	Amount (EUR)	Source
Electrolyser system		
Total system	~5.5	MTSA, and non-consortium parties
Grid connection	289.000	Liander
Oxygen treatment	459.000	Other
Subtotal	**6.396.000**	
Civil works		**W+B estimate**
Land purchase	100.000	
Hardening	12.500	

Components	Amount (EUR)	Source
Fence + Gate	16.500	
Lighting	8.000	
Office space operators	5.000	
Building	100.000	
Container	15.000	
Subtotal civil works	**257.000**	
Other costs		
Filling station	1.000.000	Westfalen estimate
Permit costs	50.000	W+B estimate
Total other costs	**1.050.000**	
Total CAPEX	**~7.500.000**	

Table 4.16 gives an overview of the operation expenditures of the system, totalling EUR 738.000 per year. Electricity consumption has been calculated based on the BoD, resulting in total annual electricity costs of EUR 415.000 (Table 4.14). The total annual grid connection fee for a 2200 kW connection comes in at EUR 124.000.

Table 4.16 OPEX

Components	Unit	Unit price	Unit/year	EUR/year
Electricity consumption:				
Electrolysis	MWh	34	10.000	340.000
Hydrogen treatment	MWh	34	519	17.636
Oxygen treatment	MWh	34	650	22.110
Utilities	MWh	34	1.026	34.884
Grid connection				
Fee for connection	EUR/kW	3,25	2.200	7.157
Fee for capacity	EUR/kW	23,28	2.200	51.216
Fee for peak capacity usage	EUR/kW	30,00	2.200	66.000
Tap water	M^3	0,9	3.800	3.420
Operation and maintenance	EUR/jaar	-	-	12.173
Labour costs operators	EUR/FTE	60.000	3	180.000
Rental office space operators		3.000	1	3.000
Total				**738.000**

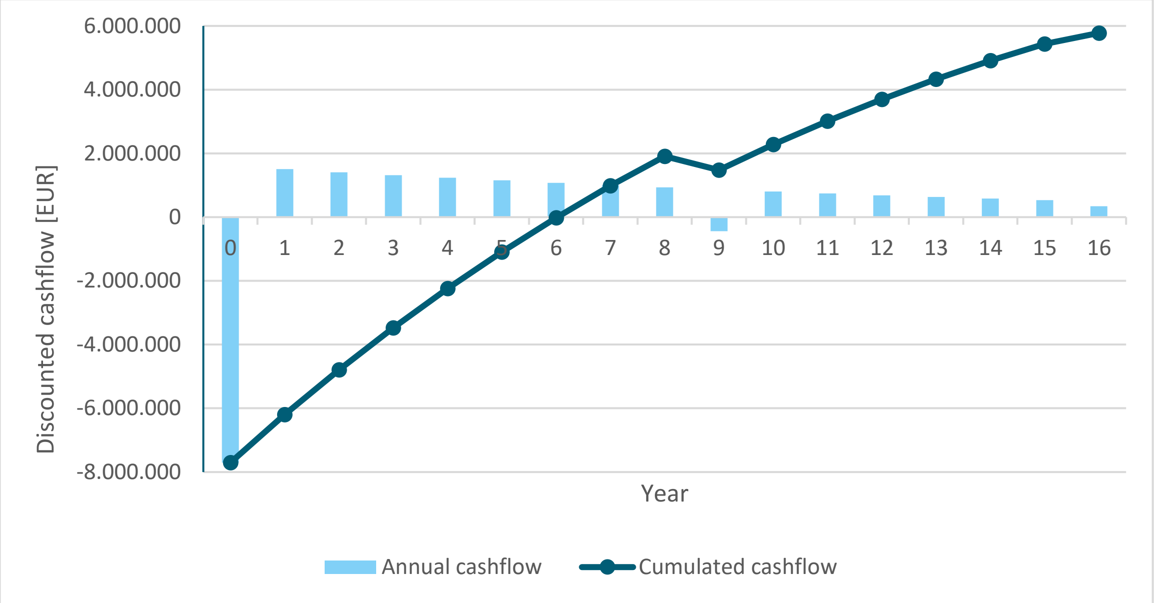
Results and cashflow

The financial results of the business case are summarized in Table 4.17 and Figure 4.14. Net Present Value (NPV) with the inputs of Table 4.14 is EUR 5.729.000, with an internal rate of return (IRR) of 13.3 %. Detailed cash flow figures are available on request.

Table 4.17 Financial results of the business case

Parameter	Value
Net present value	EUR 5.779.000
Internal rate of return	13,5 %
Payback period	5 years

Figure 4.14 Financial results of the business case



Sensitivity analysis

Figure 4.15 and Figure 4.16 and Table 4.18 show the results of the sensitivity analysis in which the following five key parameters have been changed by -20 % and +20 %: full load hours (4000; 5000; 6000), electricity price (27,2; 34; 40,8), investment costs (6.126.400; 7.703.000; 9.234.600), SDE++ (2.70; 3,34; 4,04), H_2 sales price (8; 10; 12).

No sensitivity analysis has been performed on the oxygen and waste heat sales prices, since the value of these streams is small (respectively <5 % and <2,5 % compared to H_2), therefore the impact on the business case outcome is also small.

Figure 4.15 and Figure 4.16, show the NPV and IRR in which the change compared to the base case is calculated. It can be concluded that the hydrogen sales price has the biggest impact on the overall outcome of the business case, followed by full-load hours. Investment costs, interestingly, have average effect, whereas market prices for the investment costs of the electrolyser are already lower than the costs used in this sensitivity analysis

Figure 4.15 Outcome sensitivity analyse for NPV

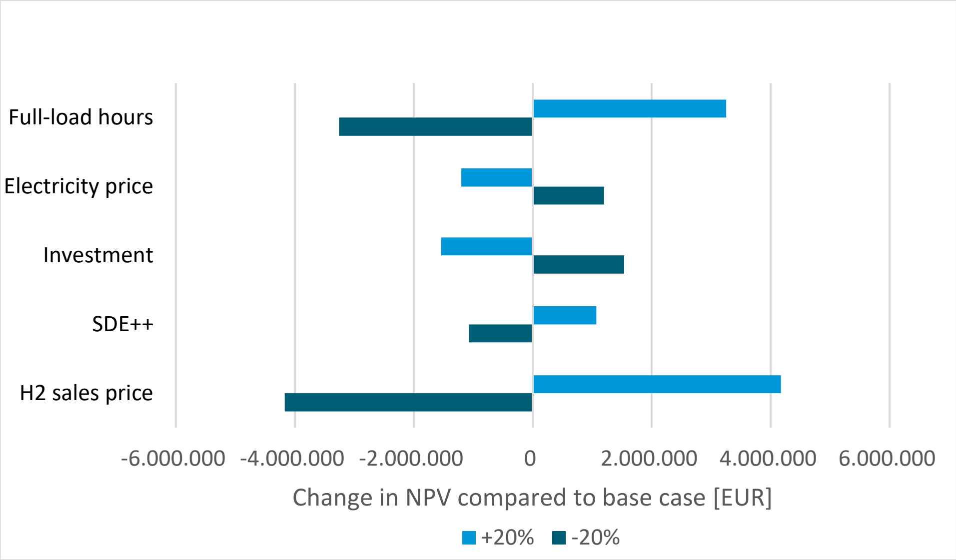


Figure 4.16 Outcome sensitivity analyse for IRR

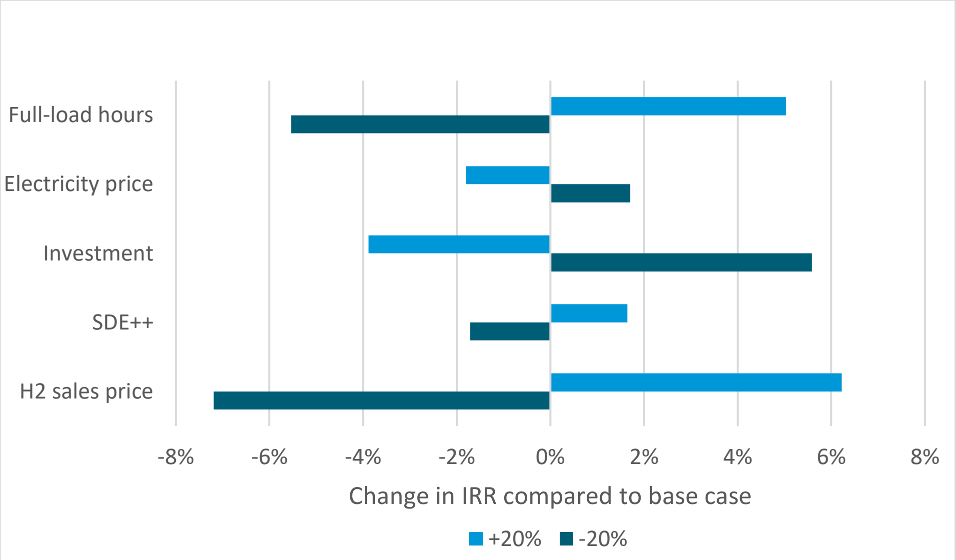


Table 4.18 Overview inputs and results sensitivity analysis

Sensitivity parameter	Variation		
	-20 %	Base case	+20 %
H2 sales price	**8**	**10**	**12**
IRR	6,3 %	13,5 %	19,7 %
NPV	€ 1.607.000	€ 5.779.000	€ 9.951.000
SDE++	**2,70**	**3,37**	**4,04**
IRR	11,8 %	13,5 %	15,1 %
NPV	€ 4.706.000	€ 5.776.000	€ 6.846.000
Investment	**6.162.400**	**7.703.000**	**9.243.600**
IRR	19 %	13,5 %	10 %
NPV	€ 7.319.000	€ 5.779.000	€ 4.238.000
Electricity price	**27,2**	**34**	**40,8**
IRR	15,2 %	13,5 %	11,7 %
NPV	€ 6.977.000	€ 5.779.000	€ 4.580.000
Full-load hours	**4000**	**5.000**	**6000**
IRR	7,9 %	13,5 %	18,5 %
NPV	€ 2.526.000	€ 5.779.000	€ 9.031.000

4.7.2 Financeability

Table 4.19 gives the Dept Service Coverage Ratio (DSCR) for the business case at different percentages of debt financing. The DSCR is a unit that shows the capacity to repay a loan based on cash flows. Conversation with Rabobank project financing specialists revealed that the DSCR for project finance should be at least 1.4, meaning a maximum of 70 % of debt financing would possible. However, since the project is using a novel electrolyser technology that doesn't have reference projects running yet, project finance would most likely not be a suitable financing option. A smaller percentage (< 50 %) might be achievable if there is another financer (such as public funding) that is willing to take on the risk.

Table 4.19 Dept service coverage ratio (DSCR) at different % of debt financing

Debt financing %	DSCR
50 %	1.9
60 %	1.6
70 %	1.4
80 %	1.2
90 %	1.1

4.7.3 Socio-economical cost benefits analysis (SCBA)

A socio-economic cost benefit analysis (SCBA) has been carried out to investigate if and how local H_2-hubs can have a positive welfare balance for society as an alternative to centralized H_2 production or H_2 import. As a reference, a simplified business case analysis (different than paragraph Business case) was performed. For this purpose, a calculation model was developed for a green electrolyzer system that does not only produce H_2, but can also sell O_2, waste heat and/or provide flexibility services for the electricity grid. With this model it is possible to determine if and to what extent the sale of other products and services than H_2 can help to improve both the socio-economical balance and the business case. It was found that both the socio-economical balance and the business case were negative, despite selling O_2 or heat in addition to selling H_2. These results are in line with paragraph Business case which shows that sales of oxygen and waste heat have very minor influence on the business case.

To find which factors determine the outcomes of cost benefit analysis and business case, various fictitious cost and selling scenarios were run. It was found that the hydrogen selling price, electricity prices and capital expenditures were the most significant parameters determining the outcomes. After running these fictitious scenarios through the model, a realistic scenario was modelled for the city of Deventer with an average H_2 price of €5, a green oxygen breakeven price, a linearly increasing CO_2 price by 5 % per year and electricity prices declining linearly from € 45 to € 22 in 2050. For this realistic case, a maximal achievable business case outcome was found to be minus € 2.8 million euro. The return on investment was 0,88. For the business case to break even, a price of € 6,71 per kg H_2 is required. This breakeven price may become lower in the near future, when capital expenditures drop due to economies of scale or when the sale of flexibility services is introduced. Preliminary results show that flexibility services may have a positive effect, but this must be elucidated on further. Concluding: selling by products oxygen or waste heat does not have a positive effect on the SCBA, flexibility services may have a positive effect, but need more investigation.

4.7.4 Conclusions

The business case for the Deventer case has a positive result. However, much of this positive result is based on the hydrogen sales price (€ 10/kg). The sensitivity analysis shows that a lower sales price will quickly decrease the NPV and IRR of the business case to low (€ 7,50/kg) or negative (€ 6/kg) values. This hydrogen sales price can be obtained by targeting small-scale sale channels in the form of 50 litre cylinders. Since Westfalen already has a large client base for these cylinders, it can form a good market-entry strategy for a first plant of this scale. If the project enters a next phase, more attention should be given to the engineering and costs of the filling station, which was quoted at a lumpsum price of 1 million EUR by Westfalen but should be detailed further.

Although the value of the oxygen and waste heat sales prices are small (respectively <5 % and <2,5 % compared to H_2), some revenue of these streams can be obtained making it a ‘business case enhancer’. Selling by-products oxygen or waste heat does not have a positive effect on the SCBA, flexibility services may have a positive effect, but need more investigation.

Financing a first-of-kind plant through project financing is difficult as financers are looking for more certainty of the long-term performance. Other financing pathways should be explored.

5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

GROHW has the ambition to design (and build!) a hydrogen system on a local scale over the entire hydrogen value chain. We distinguish ourselves from other hydrogen projects by:

1. **Green Hydrogen**. Local green hydrogen over the entire value chain is of course the main focus of GROHW. We found which parameters effect the 'green' label and implemented this knowledge in our conceptual way of thinking. We also found which components influence other components and made decision trees to define high over system designs. Lastly, we gained insights in the possibilities and the limits of a local project.
2. **Societal impact**; we aim to have social impact by:
    1. The local and collaborative character; we make impact together. We share our knowledge and help each other. Our website and LinkedIn account inform interested about hydrogen, GROHW and lessons learned. We inform the public through the broad perspective of the different partners operating in the different industries. This is with the aim of creating broad social support. We have the ambition to digitalise the blueprint such that everyone can get inspired by this approach and is able to use it.
    2. The ambition to utilise the O (oxygen), the W (waste heat), and/or to supply flexibility services. Our systems are designed in such a way that utilisation of these two products can be switched 'on' or 'off', and we therefore produce less 'waste'. We now possess a value proposition for the successful local utilisation of oxygen produced in a full-scale system. We know what type of users are likely to utilise oxygen on a local scale and how this effects the business case. In our following project - the pilot project called GROHW-2, which is already running - we even experiment with the utilisation of waste heat. Sales of oxygen and/or waste heat have a very limited to no effect on the (socio-economical) business case. Preliminary research shows that flexibility services may have a positive effect on the SCBA, however, this must be explored in more detail.
3. **Blueprint approach**; we succeeded in developing a standardised approach for:
    1. The design of the system. We know how to move from an idea to a clear scope: we know which partners are essential for a project, how to use our decision trees to draft the initial project scope, how a by all partners supported system design looks like and how this design can be evaluated.
    2. The design of an electrolyzer and the components around it on a 1 - 5 MW scale. Our design is modularly built. We can choose between different configurations: with or without heat and oxygen, without additional compression, with or without large-scale storage, different hydrogen qualities and/or using different water qualities. Also our communication strategy is modular.
    3. A Smart Energy Hub. We developed a blueprint of a digital platform in which the energy flows within a Smart Energy Hub are optimised in terms efficiency (MWh), business (Euros) and/or value case (minimal CO_2 emissions).
    4. With the scalable/modular approach to marketing communications, we want to make it possible for parties who have newly joined the consortium, to quickly and easily be included in the branding and provide tools to tell the story from their own perspective without too much extra hassle.

5.2 Recommendations

1. Test the blueprint and the GROHW design in a Smart Energy Hub context and share knowledge. A first step is already taken with the start of our demonstration project (GROHW-2) at De Gasfabriek. To let interested people experience and learn about the possibilities of green hydrogen up close, GROHW-2 will host several demo days where people can view the demo set-up and gain knowledge.
2. We want to digitalise the blueprint, such that it can be used by everyone in an efficient way. To get here, we need to think of a digital strategy, and we need to add more detail to decision trees to achieve more precise results.
3. After the demonstration project we want to develop the hydrogen system further to a full-scale hydrogen system.
4. Investigate extending/optimising the lifespan of the stacks as the most critical component in the electrolyzer.
5. Investigating the safest storage strategy for hydrogen, so that it is easier to incorporate in urban environments.
6. Ensure that the results are reflected in the RELEASE project and, conversely, take the knowledge from RELEASE to strengthen a full scale and realisation phase with the lessons learned.
7. One to Zero (OTZ): GROHW is a building block in a Smart Energy Hub concept. So start working with the partners in Smart Energy Hub Deventer that the Deventer Economic Perspective is developing and accelerate the energy transition using OneToZero.

6

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Bijlagen

Appendices

APPENDIX: REFLECTIONS ON THE DESIGN PROCESS

Appendix I - Reflections on the design process

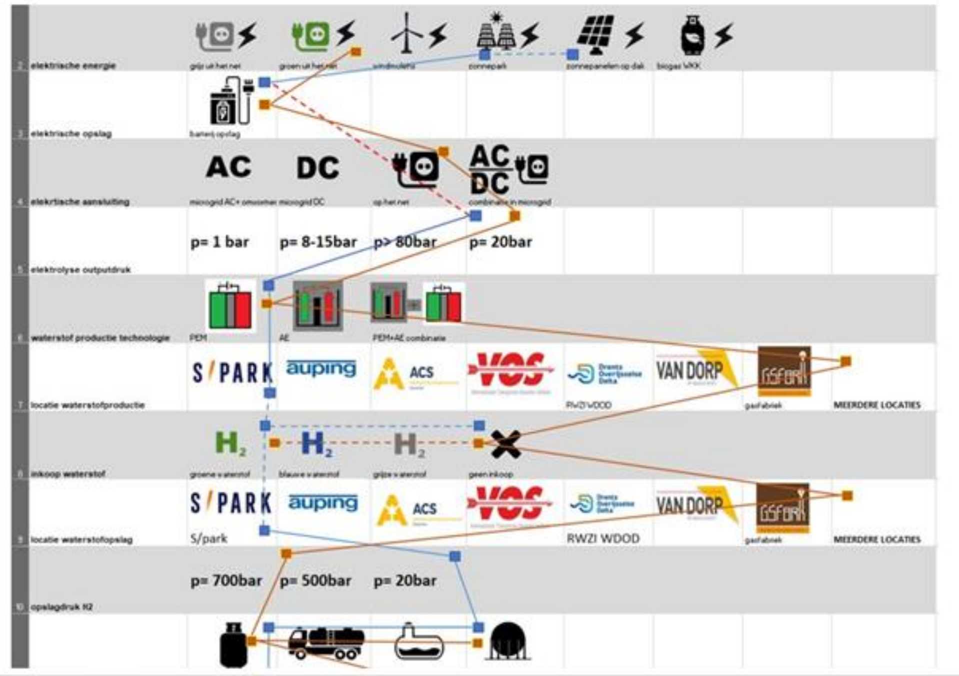
This appendix reflects on some parts of the methodology and also some tools that have been developed but not used in the final result.

1.1 Morphological scheme

A tool that resulted from the framing session was a morphological overview: a schematic overview of the technical variants for different building blocks.

Based on the ratings for the topics that were given during the framing session, scenarios were chosen that could be characterized by a line in the morphological overview (example in figure below). Thus the scenarios were characterised by different combinations of realization options.

Figure 1 - Morfological chart with scenarios



While setting up schemes for the MCA, the feeling arose that there was some inconsistency in the characterization of the scenarios. Also it became clear that the basic assumptions about (a.o.) the application of renewable energy had not been defined properly, and also that it was not specified if all demand of the customers must be supplied. Further analysis learned that this resulted from different 'levels' of characteristics: A distinction can be made between (1) independent choices and (2) characteristics that should follow from a technical and/or economic analysis.
The independent characteristics are the ones that should make up a scenario.
The others must be deduced by following a standardized procedure. For this procedure it was decided to develop decision trees for the relevant design themes (building blocks from the block diagram)
With this insight, The steps scenario definition and MCA were retraced.

1.2 Selection of criteria and weighting

This step should be taken early in the process as described in the methodology. During the project it occurred later in the process.: It revealed that for quite some partners, price of hydrogen was of crucial importance. If this had been clear earlier in the process, it could have been taken into account when defining the scenarios.

1.3 Storage tool

A tool to size the storage capacity of hydrogen based on the supply, demand and storage pressure had been developed. We have learned that the hydrogen storage capacity is very sensitive to the hydrogen supply and (simultaneous) demand of hydrogen consumers. Therefore it has been decided to size the capacity of the hydrogen storage in the basic engineering phase.

Furthermore, we have learned that the optimal storage pressure is sensitive to the location and transport method of hydrogen. These are also factors that were not decided yet. Therefore the storage pressure will also be determined in the basic engineering phase.

Hydrogen compressions is also part of this system and is therefore also considered in the basic engineering phase.

1.4 Further considerations

In the GROHW-process there has been a strong focus on technical issues. It should however be kept in mind that the motivation of the project partners to join the project is not just to realise or buy hydrogen for a reasonable price. Motivations are very probably related to (e.g.) goals on sustainability, expectation of future regulation with respect to the use of fossil fuels, or substantial CO_2-pricing. And in most cases this is not about next year, but about the longer term.

In order to do more justice to these considerations, much more attention could be given to the business case for different partners. Not just financial -, but also other considerations should be taken into account: what is the added value of taking part in the project?

By carrying out a stakeholder analysis for all partners, a better picture is obtained of what the objectives and criteria in the project should be. This would be a valuable addition that could precede the step of selection of criteria and weighting, and prevent ‘surprises’ about the result of the MCA at a late stage in the process.

II

APPENDIX: MEMO PERMITS

NOTITIE

Onderwerp	Vergunningen GROHW
Project	GROHW
Opdrachtgever	Provincie Overijssel
Projectcode	119017
Status	Concept 01
Datum	26 oktober 2020
Referentie	119017/20-016.043
Auteur(s)	M. Assink BA
Gecontroleerd door	ir. L.F.C. Steens
Goedgekeurd door	F. van de Watering PhD
Paraaf	
Bijlage(n)	-
Aan	Provincie Overijssel
Kopie	-

1 INLEIDING

GROHW werkt aan een blauwdruk voor waterstofproductie door elektrolyse op kleine schaal. Om dit mogelijk te maken moeten waterstof en zuurstof worden geproduceerd en vervolgens worden opgeslagen, waarna het getransporteerd en gebruikt zal worden. Dit document biedt een overzicht van relevante wet- en regelgeving en veiligheidsnormen voor het GROHW project. De focus ligt hierbij op productie, opslag en transport van waterstof. De tijdelijke opslag bij eindgebruikers zal gaan om kleinere volumes daardoor ligt op dit moment niet de aandacht. De informatie in dit rapport is gebaseerd op Nederlandse wetgeving vóór de intreding van de omgevingswet.

De richtlijnen/vergunningen relevant voor het GROHW project zijn opgesplitst in verschillende categorieën: natuur, milieu, veiligheid en ruimtelijke ordening. Bij het onderdeel natuur wordt ingegaan op stikstofuitstoot en de mogelijk daarmee samenhangende stikstofdepositie. Bij milieu wordt stilgestaan bij het type inrichting, het besluit m.e.r. en best beschikbare techniek. Bij veiligheid wordt de relevante wet- en regelgeving beschreven en is een indicatie contourberekening gedaan met betrekking tot het plaatsgebonden risico. In het hoofdstuk ruimtelijk ordening wordt ingegaan op de ruimtelijke inpasbaarheid van de verschillende aspecten van het GROHW project.

2 SAMENVATTING

Hieronder wordt voor de categorieën natuur, milieu, veiligheid en ruimtelijke ordening de relevante wet- en regelgeving of de veiligheidsnormen samengevat. Deze wordt later in het rapport verder toegelicht.

Natuur

Tijdens de aanlegfase van het waterstofsysteem vindt er emissie van stikstofoxiden plaats door transportbewegingen en bouwwerkzaamheden. In de gebruiksfase vindt er stikstofemissie plaats door het produceren, transporteren en gebruiken van waterstof. Een eerste inschatting is dat stikstofemissie tijdens de aanlegfase en als gevolg van het produceren en transporteren van de waterstof niet zal leiden tot een significante verhoging van de stikstofdepositie op Natura-2000 gebieden. Door het gebruiken van waterstof als brandstof is er mogelijk wel een wijziging in de stikstofdepositie. Door het gebruik van waterstof wordt het gebruik van aardgas (vermoedelijk) verminderd. Bij het verbranden van waterstof met lucht kunnen echter ook stikstofoxiden ontstaan. Om dit tegen te gaan wordt er onderzocht of verbranding met pure zuurstof mogelijk is. Er wordt dan ook gekeken naar verbranding van zowel aardgas als waterstof met pure zuurstof, zodat saldering mogelijk is. Om het verschil in NOx uitstoot en depositie betere te kunnen duiden is nog aanvullend onderzoek benodigd.

Milieu

Het opslaan en produceren van H_2 en O_2 betekent dat een inrichting vergunningplichtig is volgens het Besluit Omgevingsrecht (Bor). Hierdoor is de inrichting ook een type C inrichting volgens het activiteitenbesluit. Voor de productie geldt daarnaast dat dit onder de IPPC regelgeving valt en hier dus BBT-conclusies op van toepassing zijn. Daarnaast moet er een vormvrije m.e.r.-beoordeling worden opgesteld voortkomend uit artikel 34.4 bijlage D van het besluit m.er. voor het oprichting van een installatie voor de vervaardiging van chemicaliën.

Ruimtelijke ordening

Voor het vervaardigen van industriële gassen is milieucategorie 5 van toepassing. Er zijn vier locaties onderzocht voor het plaatsen van de electrolyser: S/park, Nefit, ACS en bedrijvenpark A1. Van de onderzochte locaties zijn S/park (categorie 5.2) en Nefit (categorie 5) hiervoor geschikt. Echter, in het bestemmingsplan van beide voorgenomen locaties zijn uitzonderingsgronden opgenomen. Hierin staat bijvoorbeeld dat inrichtingen die zijn genoemd in onderdelen C en D van de bijlage bij het Besluit milieueffectrapportage uitgezonderd zijn. Dit betekent dat de electrolyser niet per definitie past binnen het bestemmingsplan. Er zal dus een afwijking of een wijziging van het bestemmingsplan moeten worden aangevraagd.

Veiligheid

Bij het onderdeel veiligheid is onder andere stilgestaan bij de BRZO regelgeving. Hieruit volgt dat indien de ‘base case’ (met als uitgangspunt dat productie en opslag van waterstof op één centrale locatie plaatsvindt) gehanteerd wordt, de hoeveelheid waterstof die wordt opgeslagen de lage drempelwaarde (5 ton waterstof) overschrijdt, en het project hiermee onder de BRZO regelgeving valt. Dit betekent dat het project per definitie ook onder het Bevi valt. Het oprichten van een nieuwe Bevi inrichting is conform de bestemmingsplannen (van zowel S/park als Nefit niet per definitie toegestaan; een wijziging van het bestemmingsplan is dan ook noodzakelijk. Bij het inpassen van een Bevi inrichting in het bestemmingsplan en het verlenen van een omgevingsvergunning, moet er rekening gehouden met veiligheidsafstanden tussen de inrichting en gevoelige objecten. Daarom zijn er via Safeti-NL (indicatieve) risico berekeningen gedaan. De uitgangspunten en de berekende risicocontouren zijn in paragraaf 5.2.1 beschreven.

Overzicht

In onderstaande tabel is overzichtelijk uiteengezet welke wet- en regelgeving relevant is voor het GROHW project. Hierin is onderscheid gemaakt tussen het opslaan en produceren van zowel H_2 als O_2.

Tabel 2.1 Samenvatting regelgeving op toepassing van verschillende aspecten van het GROHW project

Wet/voorschrift	H2 Productie	H2 Opslag	H2 Transport	O2 Productie	O2 Opslag	O2 Transport
inrichting C		X			X	
inrichting C - IPPC	X			X		
milieucategorie 3		X			X	
milieucategorie 4		indien compressor aanwezig			indien compressor aanwezig	
milieucategorie 5	X			X		
MER(beoordelings)-plichtig	X		indien leiding door Natura 2000 gebied		indien leiding door Natura 2000 gebied	
Brzo		indien >5 ton				
Bevi*		indien >13 m3 *				

* Wanneer het Brzo van toepassing is valt de installatie automatisch ook onder het Bevi (volgens Bevi art. 2.1.a).

3 UITGANGSPUNTEN

Op dit moment is het nog niet bekend hoe de waterstofinstallatie er precies uit komt te zien. Er zijn verschillende mogelijkheden voor de methode van productie, opslag en transport van waterstof. Op dit moment wordt de 'base case' als uitgangspunt genomen. Hierbij is het uitgangspunt dan alle waterstof met electrolysers wordt geproduceerd op één centrale locatie. Op deze locatie wordt de waterstof als gas onder druk opgeslagen en van daaruit getransporteerd naar de verschillende gebruikers. Dit transport kan plaatsvinden via de weg of via een pijpleiding.

4 MILIEU ASPECTEN

4.1 Aard van de inrichting

Het Activiteitenbesluit kent 3 soorten inrichtingen: type A, B en C.
- type A : Welke inrichtingen type A zijn staat in artikel 1.2 van het Activiteitenbesluit.;
- type B: Alle inrichtingen die niet type A of C zijn;
- type C: Alle inrichtingen die een omgevingsvergunning milieu moeten hebben volgens het Besluit omgevingsrecht bijlage 1 onderdeel C.

De verschillen tussen inrichtingen type A, B en C zijn als volgt:

Type A
Inrichtingen type A zijn inrichtingen die minder milieubelastende activiteiten uitvoeren. Ze hoeven bij de oprichting of een wijziging geen melding te doen aan het bevoegd gezag. Ook hebben ze geen omgevingsvergunning milieu nodig. Deze bedrijven vallen wel onder het activiteitenbesluit en moeten voldoen aan de relevante voorschriften uit het activiteitenbesluit.

Type B
Inrichtingen type B zijn inrichtingen die bij de oprichting of een wijziging een melding moeten doen aan het bevoegd gezag. Ze hebben geen omgevingsvergunning milieu nodig. Soms hebben ze een omgevingsvergunning beperkte milieutoets (OBM) nodig. Deze bedrijven vallen wel onder het activiteitenbesluit en moeten voldoen aan de relevante voorschriften uit het activiteitenbesluit.

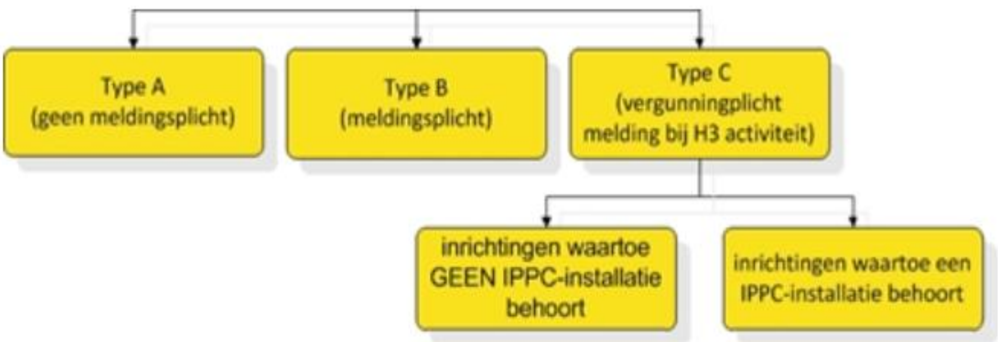
Type C
Inrichtingen type C zijn inrichtingen die een omgevingsvergunning milieu nodig hebben volgens het Besluit omgevingsrecht. Ze moeten een melding Activiteitenbesluit doen voor activiteiten waarop hoofdstuk 3 van het Activiteitenbesluit van toepassing is. Voor die activiteiten hoeven dan geen voorschriften in de vergunning te staan.

Bij dit project is er sprake van opslag en productie van zowel waterstof als zuurstof. De inrichting is vergunningplichtig volgens het Besluit omgevingsrecht, bijlage I onderdeel C, op grond van de volgende categorieën:
- de productie van waterstof is vergunningplichtig op grond van cat. 4.4b (productie van gevaarlijke stoffen). Waterstof is een brandbaar gas en dus een gevaarlijke stof;
- opslag van waterstof in tanks valt onder cat. 2.7 i. Wanneer er wordt gekozen om waterstof niet in tanks, maar in gasflessen op te slaan, valt de opslag niet onder deze categorie;
- opslag van zuurstof valt onder cat. 2.7 g, mits het totale volume meer dan 100 m^3 bedraagt en zuurstof in tanks wordt opgeslagen.

De inrichting voor het vervaardigen van waterstof betreft ook een inrichting waartoe een IPPC-installatie behoort. De installatie valt volgens EU richtlijn Industriële emissies (2010/72/EU) onder categorie artikel 4.2: De fabricage van anorganisch-chemische producten, zoals:
- a) gassen, zoals ammoniak, chloor of chloorwaterstof, fluor of fluorwaterstof, kooloxiden, zwavelverbindingen, stikstofoxiden, waterstof, zwaveldioxide, carbonylchloride,

Voor de IPPC-installaties gelden BBT-conclusies en BREF’s. Deze zijn in paragraaf 3.3 nader beschreven.

Afbeelding 4.1 Bron: Infomill



Ongeacht de locatie moet er een vergunning aanvraag voor type C (IPPC) inrichting worden gedaan voor de productie van waterstof. In het geval dat de inrichting vanwege andere activiteiten al een vergunning heeft moet er een wijzigingsvergunning worden aangevraagd. Voor het opslaan van waterstof in tanks is eveneens een vergunning nodig. waterstof wordt opgeslagen in tanks. Voor het opslaan van zuurstof in tanks is een vergunning nodig indien de opslaggezamenlijk >100 m^3 is. Voor de opslag van waterstof of zuurstof in gasflessen is geen vergunning nodig.

Dit betekent dat in ieder geval rekening moet worden gehouden met een proceduretermijn van 6 maanden, vanaf moment van indienen van de definitieve aanvraag tot het verkrijgen van de definitieve vergunning[1]. Zuurstof opslag tot 100 m^3 is type B-inrichting en heeft dus geen omgevingsvergunning nodig maar moet wel voldoen aan het melden van wijziging/oprichting van de inrichting aan het bevoegd gezag. Wanneer de opslag plaatsvindt bij een inrichting welke al over een vergunning beschikt moet een wijzigingsvergunning worden aangevraagd.

4.2 Besluit MER

In het Besluit MER (Milieu Effecten Rapportage) zijn categorieën aangewezen die MER-plichtig (onderdeel C) of m.e.r.beoordelingsplichtig zijn (onderdeel D).

De GROHW activiteiten vallen in de volgende categorie:

D34.4
De oprichting, wijziging of uitbreiding van een installatie, behorend tot de chemische industrie, bestemd voor de behandeling van tussenproducten en vervaardiging van chemicaliën.

Voor de in onderdeel D opgenomen activiteiten geldt een m.e.r.-beoordelingsplicht. Echter is er bij categorie D 34.4 in kolom 2 een indicatieve drempelwaarde van 100.000 ton per jaar of meer aan productiecapaciteit opgenomen. Daarbij wordt verondersteld dat bij een lagere productiecapaciteit geen belangrijke nadelige milieugevolgen zullen optreden waardoor er volstaan kan worden met een ‘lichtere’ vormvrije m.e.r.-beoordeling, zie artikel 2, lid 5, onder b van het Besluit m.e.r.

Voor de vormvrije m.e.r.-beoordeling gelden nagenoeg dezelfde procedurele eisen als voor de formele m.e.r.-beoordeling. Voor elke aanvraag waarbij een vormvrije m.e.r.-beoordeling aan de orde is moet:
- door de initiatiefnemer een aanmeldingsnotitie worden opgesteld (Artikel 7.16 Wm);
- het bevoegd gezag binnen 6 weken een m.e.r.-beoordelingsbesluit nemen (7.17, eerste tot en met vierde lid. Dit besluit hoeft niet in de Staatscourant gepubliceerd te worden;
- de initiatiefnemer het (vormvrije) m.e.r.-beoordelingsbesluit bij de vergunningaanvraag voegen (Artikel 7.28 Wet milieubeheer tweede lid).

Indien gekozen wordt voor de toepassing van buisleidingen voor transport zijn er nog twee andere categorieën mogelijk van toepassing:

C 8-1
De aanleg, wijziging of uitbreiding van een buisleiding voor het transport van gas, olie, chemicaliën of voor het transport van kooldioxide (CO_2) stromen ten behoeve van geologische opslag, inclusief de desbetreffende pompstations. In gevallen waarin de activiteit betrekking heeft op een buisleiding met een diameter van meer dan 80 centimeter en een lengte van meer dan 40 kilometer.

D 8-1
De aanleg, wijziging of uitbreiding van een buisleiding voor het transport van gas, olie of CO2-stromen ten behoeve van geologische opslag of de wijziging of uitbreiding van een buisleiding voor het transport van

[1] Genoemde 6 maanden zijn dus exclusief vooroverleg (vóór indienen van de vergunningaanvraag) en exclusief eventuele bezwaarprocedure (na verkrijgen van de definitieve vergunning).

chemicaliën. In gevallen waarin de activiteit betrekking heeft op een buisleiding die is gelegen of geprojecteerd in een Natura 2000 gebied, over een lengte van:
- 1°.1 kilometer of meer, in geval van het transport van olie, CO2-stromen of gas, niet zijnde aardgas;
- 2°.5 kilometer of meer, in geval van het transport van aardgas.

4.3 Richtlijn industriële emissies

Aangezien de elektolyser in het GROHW project een IPPC installatie is, zijn er BBT's en BREF's van toepassing. De volgende BREF's en BBT's zouden van toepassing kunnen zijn bij een type 4.2 IPPC installatie:
- BBT-conclusies voor de Chlooralkali industrie;
- BREF Anorganische bulkchemicaliën - ammoniak, zuren en kunstmest;
- BREF Anorganische fijnchemicaliën;
- BREF Anorganische Bulkchemie - vast en overig;
- BREF Koelsystemen;
- BBT-conclusies afgas- en afvalwaterbehandeling;
- BREF Op- en overslag bulkgoederen;
- BREF Energie-efficiëntie.

Geen enkele van deze documenten bevat specifiek BBT conclusies voor de productie van waterstof via een electrolyser[1]

5 RUIMTELIJKE ORDENING

5.1 Mogelijke locaties

Op dit moment ligt de locatiekeuze voor de productie en opslag van waterstof nog niet vast. Daarom worden de volgende locaties op dit moment onderzocht:
- Auping;
- Vos;
- S/park;
- Nefit Industrial;
- ACS.

5.2 (Afwijken) bestemmingsplan - milieu categorie

Voor dit onderdeel van de notitie is er van uitgegaan, dat de productie en opslag in het GROHW project als bedrijf moet worden gezien, zoals doorgaans gedefinieerd in het bestemmingsplan. Dit betekent dat de productie/opslag zonder afwijking van het bestemmingsplan alleen in die gebieden kan worden gerealiseerd, die in het bestemmingsplan zijn aangewezen voor de bestemming bedrijfsdoeleinden.

Voor de plaatsing binnen deze aangewezen gebieden zijn de milieucategorieën van belang, zoals opgenomen in de VNG publicatie "Bedrijven en milieuzonering"[2]. Hierin zijn de meest voorkomende bedrijfsactiviteiten onderverdeeld in bedrijfscategorieën, afhankelijk van de milieubelasting, waarbij ook het aspect externe veiligheid is meegenomen. De VNG publicatie onderscheidt enerzijds een lijst met bedrijfstypen (op basis van SBI code) en anderzijds een lijst met opslagen en installaties.

[1] De BREF Chlooralkali bevat weliswaar een beschrijving van een elektrolyzer waarbij waterstof ontstaat, maar dat proces is gebaseerd op de elektrolyse van zout voor de productie van chloor. Waterstof ontstaat daarbij als bijproduct en er zijn geen specifieke BBT conclusie opgenomen voor de productie en opslag van waterstof.

[2] https://vng.nl/onderwerpenindex/ruimte-en-wonen/omgevingswet/publicaties/handreiking-bedrijven-en-milieuzonering.

In deze VNG publicatie wordt ingegaan op:
- opslagen met bedrijfscategorie 3, die niet 1:1 van toepassing zijn, maar wel als zodanig kunnen worden uitgelegd[1];
- een compressorstation met vermogen <100 MW voor (categorie 4);
- Het vervaardiging van industriële gassen; explosief (categorie 5).

Gelet op bovenstaande wordt geadviseerd om er rekening mee te houden dat de electrolyser van het GROHW project als bedrijfscategorie 5 wordt aangemerkt. In dat geval kan GROHW zonder afwijking alleen in die zones van een bedrijventerrein worden geplaatst, die voor bedrijfscategorie 5 zijn aangewezen. Voor locaties waarop een andere milieucategorie/geen bestemming bedrijfsdoeleinden van toepassing is, zal voor de plaatsing van de electrolyser/opslag een afwijking van het bestemmingsplan moeten worden aangevraagd. Wanneer een compressor station op het terrein van de opslag unit aanwezig is zal er (mogelijk) milieucategorie 4 nodig zijn. Mocht dit niet het geval zijn voldoet categorie 3.

Tabel 5.1 Overzicht bestemmingsplannen potentiële locaties GROHW

Locatie	Bestemmingsplan	Milieucategorie
Auping	digitalisering analoge bestemmingsplannen	4
Vos	Bergweide, Kloosterlanden - Hanzepark, Veenoord	4
S/Park	Bergweide, Kloosterlanden - Hanzepark, Veenoord	chemisch bedrijf in milieucategorie 5.2
Nefit Industrial	Bergweide, Kloosterlanden - Hanzepark, Veenoord	5
ACS	Bergweide, Kloosterlanden - Hanzepark, Veenoord	4

Het bestemmingsplan voor S/Park geeft nadrukkelijk toestemming voor[2]:
- chemisch bedrijf in milieucategorie 5.2 en in de bij het bestemmingsplan toegevoegde staat van bedrijven is ook de productie van industriële gassen benoemd (SBI-2008 2011-2/3).

Het bestemmingsplan van Nefit geeft toestemming voor bedrijven in categorie 5.1.

Zowel voor het S/park als het terrein van Nefti zijn uitzonderingsgronden opgenomen:
- inrichtingen die zijn genoemd in onderdelen C en D van de bijlage bij het Besluit milieueffectrapportage;
- Bevi inrichtingen, behoudens de bestaande.

Dit betekent dat het plaatsen van een electrolyser niet per definitie is toegestaan volgens het bestemmingsplan, aangezien deze valt onder artikel 34.4 bijlage D van het Besluit m.e.r.. Daarnaast is het waarschijnlijk dat de inrichting onder het Besluit risico's zware ongevallen (Brzo) zal vallen en daarmee een Bevi inrichting wordt.

Omdat de locatie van productie/opslag nog niet vastligt, zijn de bestemmingsplannen nog niet bekend. Daarom is op dit moment nog geen duidelijkheid over:
- de bepalingen uit het bestemmingsplan inzake maximale bouwhoogte, bebouwingspercentage, toegestane bedrijfscategorie, etc.;
- de mogelijkheden voor binnenplanse afwijking.

1 Dit betreft de opslag van 2-8 m³ butaan, propaan of PLG in bovengrondse tanks.

2 https://www.ruimtelijkeplannen.nl/documents/NL.IMRO.0150.D119-VG04/r_NL.IMRO.0150.D119-VG04_2.5.html.

6 VEILIGHEID

6.1 Brzo

Inrichtingen waarop het Besluit risico's zware ongevallen 2015 (BRZO) van toepassing is, zijn vergunningplichtig, los van de eventuele vergunningplicht ingevolge het Bor zoals in de vorige paragraaf besproken. Inrichtingen die onder het Brzo 2015 vallen, moeten aan extra verplichtingen voldoen, die niet uit het Bor volgen. Daarom wordt in deze paragraaf onderzocht of GROHW electrolyser en H2 opslag onder het Brzo 2015 valt.

Een inrichting valt onder het Brzo 2015, indien[1]:
- de hoeveelheid aanwezige gevaarlijke stoffen en mengsels groter is dan de drempelwaarden uit bijlage I van de Europese Seveso III-richtlijn.

Waterstof en zuurstof worden gespecificeerd in bijlage I van de genoemde richtlijn. In onderstaande tabel worden de drempelwaarden voor waterstof en zuurstof uit deze richtlijn getoond.

Tabel 6.1 Hoeveelheid gevaarlijke stoffen drempelwaarden Brzo 2015 (alles in ton)

Gevaarlijke stof	Lage drempelwaarde Brzo 2015	Hoge drempelwaarde Brzo 2015
waterstof	5	50
zuurstof	200	2000

Wanneer de hoeveelheid H2 in de inrichting (het gaat hierbij om vergunde hoeveelheid, niet om daadwerkelijke hoeveelheid die op een bepaald moment in de inrichting aanwezig is) dus groter is dan 5 ton zal de Brzo lage drempelwaarde worden overschreden en wanneer meer dan 50 ton aanwezig is de hoge drempelwaarde.
- **lagedrempelinrichting**: inrichting die alleen de lage drempelwaarde uit bijlage I van de Seveso III-richtlijn overschrijdt. Deze inrichting moet alle maatregelen treffen die nodig zijn om zware ongevallen te voorkomen en de gevolgen daarvan voor mens en milieu te beperken. Daarnaast moet het bedrijf een Preventiebeleid Zware Ongevallen opstellen en voor de uitvoering en bepaling daarvan een veiligheidsbeheerssysteem implementeren. Ook vinden er jaarlijks BRZO inspecties door de overheid plaats;
- **hogedrempelinrichting**: inrichting die ook de hoge drempelwaarde uit bijlage I van de Seveso III-richtlijn overschrijdt. Deze inrichting moet, naast de verplichtingen voor de lagedrempelinrichtingen, een veiligheidsrapport indienen, waarmee wordt aangetoond dat de preventie en de beheersing van de gevaren van zware ongevallen in orde zijn. Daarnaast moet er ook een intern noodplan worden opgesteld voor zware ongevallen binnen het bedrijf.

Het Besluit omgevingsrecht (Bor) en de Ministeriële regeling omgevingsrecht (Mor) stellen eisen aan de aanvraag voor de Omgevingsvergunning van een bedrijf dat Brzo-plichtig is. Relevante artikelen staan onder meer in hoofdstuk 4 (artikel 4.6) van het Bor en hoofdstuk 4 (artikel 4.13 en 4.18) van het Mor.

6.2 Bevi

Net als bij het Brzo 2015 zijn inrichtingen waarop het Besluit externe veiligheid inrichtingen (hierna: Bevi) van toepassing is, vergunningplichtig. Ook moeten inrichtingen die onder het Bevi vallen, aan extra

[1] http://www.infomil.nl/onderwerpen/hinder-gezondheid/veiligheid/brzo-2015/.

verplichtingen voldoen. Daarom wordt in deze paragraaf onderzocht of productie en opslag voor het GROHW project onder het Bevi valt.

Een inrichting valt onder andere onder het Bevi indien:
- meer dan 150 m^3 licht ontvlambare vloeistof of zeer licht ontvlambare vloeistof aanwezig is in een bovengronds insluitsysteem;
- inrichtingen waar propaan aanwezig is in een insluitsysteem met een inhoud van:[1]
- meer dan 13 m^3 propaan en ten hoogste 50 m^3 en met een jaarlijkse doorzet van meer dan 600 m^3;
- meer dan 50 m^3;
- inrichtingen waarop het Brzo van toepassing is.

Waterstof is zeer licht ontvlambaar, wanneer in de opslag dus meer dan 150 m^3 vloeistof aanwezig is valt dit onder het Bevi. Het uitgangspunt in de base case is echter dat de waterstof niet als vloeistof wordt opgeslagen, maar als gas onder druk.

In het Bevi staat de verplichting om veiligheidsafstanden aan te houden tussen gevoelige objecten en risicovolle bedrijven. Binnen het Bevi wordt een onderscheid gemaakt tussen categoriale inrichtingen en niet categoriale inrichtingen. In het geval van een categoriale inrichting zijn veiligheidsafstanden al bepaald en vastgelegd in de Regeling externe veiligheid inrichtingen (Revi). Inrichtingen voor productie en opslag van waterstof zijn niet-categoriaal en de veiligheidsafstanden zullen dus moeten worden berekend met een kwantitatieve risicoanalyse (QRA). In het Revi is vastgelegd welke methodiek moet worden gevolgd (‘Rekenmethodiek Bevi’).

Met behulp van het (wettelijk voorgeschreven) programma Safeti-NL kan de effectafstand van alle installaties worden bepaald. Indien de effectafstanden buiten de terreingrens vallen, dienen ook risicoberekeningen uitgevoerd te worden. Dit is nodig om te kunnen toetsen aan de in het Bevi opgenomen grens- en richtwaarden van het plaatsgebonden risico en het bepalen en verantwoorden van het groepsrisico.

6.2.1 Plaatsgebonden risico

In artikel 1 van het Besluit externe veiligheid inrichtingen is een definitie opgenomen van het plaatsgebonden risico (PR). Het PR is het risico (uitgedrukt in kans per jaar) dat één persoon die zich onafgebroken en onbeschermd op die plaats bevindt, overlijdt als rechtstreeks gevolg van een calamiteit met een gevaarlijke stof. In het besluit is een norm opgenomen voor het plaatsgebonden risico. Deze norm is een grenswaarde voor kwetsbare objecten en moet daarom door het bevoegde gezag in acht worden genomen (mag niet van worden afgeweken).

Het plaatsgebonden risicocontour 10^{-6}/jr geldt als richtwaarde voor beperkt kwetsbare objecten en als grenswaarde voor kwetsbare objecten. Dit betekent dat kwetsbare objecten niet binnen deze contour aanwezig mogen zijn of mogen komen. Beperkt kwetsbare objecten zijn alleen toegestaan als daarvoor voldoende motivatie is gegeven.

In artikel 1, eerste lid, onderdelen b en l, van het Bevi staat wat een beperkt kwetsbaar object en een kwetsbaar object is. Kenmerken van kwetsbare objecten zijn:
- de aanwezigheid van of grote groepen mensen of;
- verminderd zelfredzame personen als kinderen, gehandicapten en ouderen.

Grootte van PR contouren
Met gebruik van het programma Safeti-NL zijn risicoberekeningen uitgevoerd. Om deze berekeningen uit te kunnen voeren is een ‘base case’ als uitgangspunt gehanteerd. In onderstaande tabel zijn de uitgangspunten weergegeven.

[1] Dit kan als waterstof kunnen worden uitgelegd.

Tabel 6.2 Uitgangspunten

Type	Waarde
druk	350 bar
type opslag	270 L vaten
	Rijen van 25 vaten
	2 rijen (50 vaten) per container
Centrale opslag	
totale opslag	6165 kg
aantal vaten	965
aantal rijen	39
aantal containers	20
Decentrale opslag bij gebruiker	
totale opslag	483 kg
aantal vaten	75
aantal rijen	3
aantal containers	2

Contour
In onderstaande tabel is de PR contour van zowel de centrale als decentrale opslag weergegeven. De berekeningen zijn gemaakt op basis van bovenstaande uitgangspunten. Omdat er nog geen exacte locatie bekend is zijn de contouren nog niet gevisualiseerd.

Tabel 6.3

Onderdeel	Centrale opslag PR 10^{-6} contour (radius)	Decentrale opslag PR 10^{-6} contour (radius)
storage	20 m	17 m
transportation truck	<5 m	< 5 m
storage + Loading	22 m	21 m

Factoren van invloed op PR contouren

- opstelling en type tanks:
  - de grootte van de PR contouren hangt af van de hoeveelheid waterstof die wordt opgeslagen en de grootte van de tanks (vooral dit laatste blijkt veel invloed te hebben. Het is gebruikelijk bij de opslag van waterstof dat de verschillende vessels of cilinders met elkaar zijn verbonden. De risicocontouren worden ook beïnvloed door hoe dit systeem werkt. Als één cilinder faalt, komt er dan ook waterstof vrij uit de andere verbonden cilinders? Is de kans groot dat deze ook falen?
- verladen:
  - verladen heeft invloed om de grootte van de PR contouren. De straal hangt af van de soort laadpijp dat gebruikt wordt, het aantal uur per jaar dat de verladingsactiviteiten plaatsvinden en de hoeveelheid waterstof die vrij kan komen wanneer de pijp breekt (wat weer afhangt van hoe de vessels met elkaar verbonden zijn en hoe het systeem is beveiligd).

Uit voorlopige berekeningen blijkt dat de vooral de grootte van de laadslang een grote invloed heeft op de risicocontouren. Ook het aantal uren per jaar kan een groot effect hebben, maar dit is pas significant als het onder de 50 uur per jaar komt (ongeveer). Het verschil tussen bijvoorbeeld 100 of 600 uur per jaar is klein (ca 1 m). Op basis van de eerste indicatieve berekeningen kan dus gesteld worden dat wanneer de laadslang groter wordt de contour ook groter wordt, ondanks dat er sneller geladen en gelost kan worden.

6.2.2 Groepsrisico

De grens van het invloedsgebied van een inrichting is 1% letaliteit. Met groepsrisico wordt de cumulatieve kansen per jaar dat ten minste 10, 100 of 1000 personen overlijden als rechtstreeks gevolg van hun aanwezigheid in het invloedsgebied van een inrichting en een ongewoon voorval binnen die inrichting waarbij een gevaarlijke stof betrokken is bedoeld.

Deze definitie impliceert een tweetal aspecten die (rechtstreeks) invloed uitoefenen op de hoogte van het groepsrisico:

- de jaarlijkse kans dat zich een ongeval voordoet met gevaarlijke stoffen. Deze grootheid is op zichzelf weer afhankelijk van:
  - de opslag methode;
  - de aard en omvang van de gevaarlijke stoffen;
  - de daarmee verrichte handelingen;
  - de wijze waarop een inrichting omgaat met veiligheid;
- het aantal potentiële dodelijke slachtoffers in de omgeving van de activiteit. Dit hangt af van:
  - de samenstelling (hoeveelheid én spreiding) van de bevolking;
  - de effecten van een stof in geval van een ongeluk;
  - de mogelijkheden tot zelfredzaamheid en bestrijding van de gevolgen.

Hierbij kan sprake zijn van een ‘uitgebreide’ of een ‘beperkte’ verantwoordingsplicht. Bij de uitgebreide variant gelden alle elementen zoals die bij de verantwoordingsplicht in het Bevi worden genoemd. Bij de beperkte variant wordt enkel ingegaan op de hoogte van het groepsrisico, mogelijkheden tot voorbereiding van bestrijding en beperking van een ramp en de mogelijkheden tot zelfredzaamheid.

QRA

QRA (kwantitatieve risico analyse) is een methode om het groepsrisico en plaatsgebonden risico uit te rekenen. De rekenmethodiek Bevi is verplicht voor Bevi inrichtingen en is vastgelegd in het Revi. Het invloedsgebied is het gebied dat relevant is voor de berekening van het groepsrisico. Het invloedsgebied voor inrichtingen waar een QRA voor opgesteld moet worden, wordt begrensd door de 1 %- letaliteitgrens.

7 NATUUR

7.1 PAS

Het PAS (Programma Aanpak Stikstof) bood ruimte om vergunningen voor (bouw) projecten met stikstofdepositie op Natura-2000 gebieden te verlenen ondanks een overschrijding van de maximale hoeveelheid stikstof uitstoot. In 2019 is een streep door de PAS gezet. Dit betekent dat bij het verkennen van de locatie voor het GROHW project rekening gehouden dient te worden met de hoeveelheid stikstof die uitgestoten wordt binnen het project.

7.2 Natura 2000 gebieden

Op onderstaande afbeelding zijn, in groen, de Natura 2000 gebieden in en rondom Deventer aangegeven. Hieruit is zichtbaar dat de beoogde locaties voor de electrolyser en/of opslag van waterstof niet in een Natura 2000 gebied liggen maar er wel diverse Natura 2000 gebieden in de omgeving liggen. Het aspect stikstofuitstoot is daarmee een relevant projectrisico. Een nadere beschouwing van de stikstofuitstoot, met name in de gebruiksfase, zal meer inzicht bieden in de daadwerkelijke gevolgen voor dit project.

Een eerste inschatting is dat de bouw van de voorzieningen en de productie niet tot een significante extra stikstofdepositie zullen zorgen op de naastgelegen natuurgebieden. Het transport van waterstof met vrachtwagens, zal wel tot uitstoot leiden maar de ervaring leert dat de daadwerkelijke depositie van vrachtverkeer beperkt is. Daarnaast gaat het vrachtverkeer al snel op in regulier verkeer voor welke depositie dit project niet verantwoordelijk is.

Het gebruik van waterstof als brandstof zal wel tot uitstoot van NOx leiden. Het is realistisch aan te nemen dat een deel van deze uitstoot zal leiden tot depositie op naastgelegen Natura-2000 gebieden. Het gebruik van waterstof als brandstof zal leiden tot een reductie van het gebruik van aardgas waardoor de depositie door het gebruik van waterstof (deels) kan worden gesaldeerd. Voor de implementatie van waterstof als brandstof zal hier nader onderzoek naar gedaan moeten worden.

Afbeelding 7.1 Natura 2000 gebieden Deventer

8 VEILIGHEIDS RICHTLIJNEN

Bij de productie, opslag en het transport van waterstof (en zuurstof) dient rekening gehouden te worden met een aantal geldende veiligheidsrichtlijnen. Deze richtlijnen en de toepassing er van op het GROHW project staan in dit hoofdstuk toegelicht.

8.1 PGS 35

De PGS (Publicatiereeks Gevaarlijke Stoffen) 35 is een richtlijn voor de arbeidsveilige, milieuveilige en brandveilige toepassing van installaties voor het afleveren van waterstof aan voertuigen en werktuigen. Voor het GROHW project is deze richtlijn met name van toepassing op de opslag van waterstof.

8.2 PGS 15

De PGS 15 is een richtlijn voor kleinschalige opslag en tijdelijke opslag met betrekking tot brandveiligheid, arbeidsveiligheid en milieuveiligheid. Dit is voor GROHW op toepassing voor de opslag van waterstof en zuurstof wanneer op kleine schaal wordt opgeslagen (flessen).

8.3 PGS 37

De PGS 37 bevat de veiligheidseisen die gelden voor de opslag van elektriciteit in Lithium-ion batterijen. Het PGS 37 zal vanaf medio 2020 van kracht zijn. Voor het GROHW project is dit van toepassing wanneer deze opslagtechniek gebruikt zal worden.

8.4 ADR

Het ADR is een Europese overeenkomst voor het internationale vervoer van gevaarlijke goederen over de weg. Dit is voor GROHW dus van toepassing op het transport van zuurstof en waterstof.

8.5 ATEX

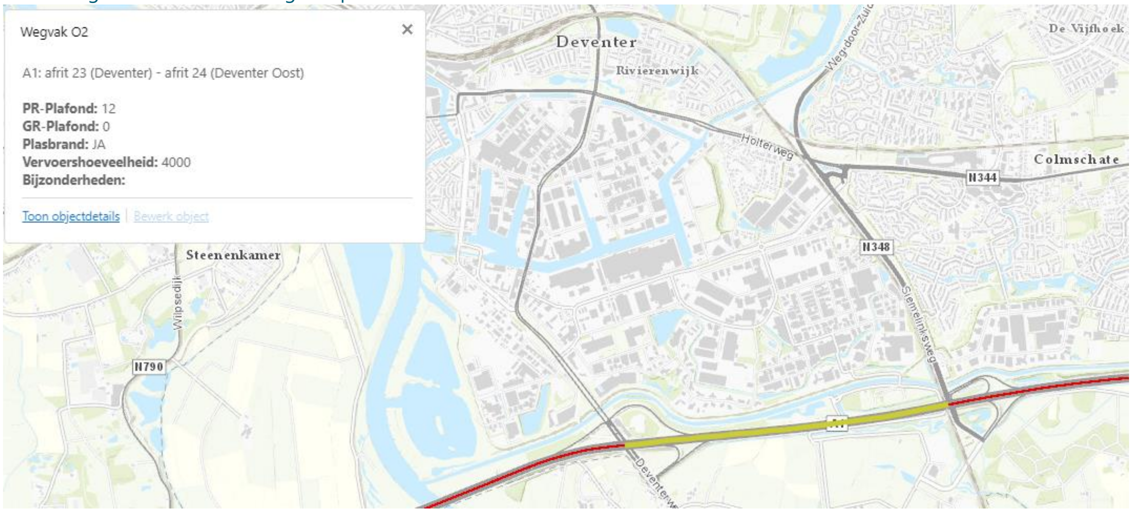
De ATEX (ATmospheres EXplosives) gaat om de beheersing van de omstandigheden in een explosieve atmosfeer, in situaties waarbij het niet mogelijk is om door vervanging van stoffen het explosiegevaar weg te nemen. Dit is voor het GROHW project toepasbaar op de productie van waterstof en de opslag/transport van zowel zuurstof als waterstof.

8.6 Basisnet

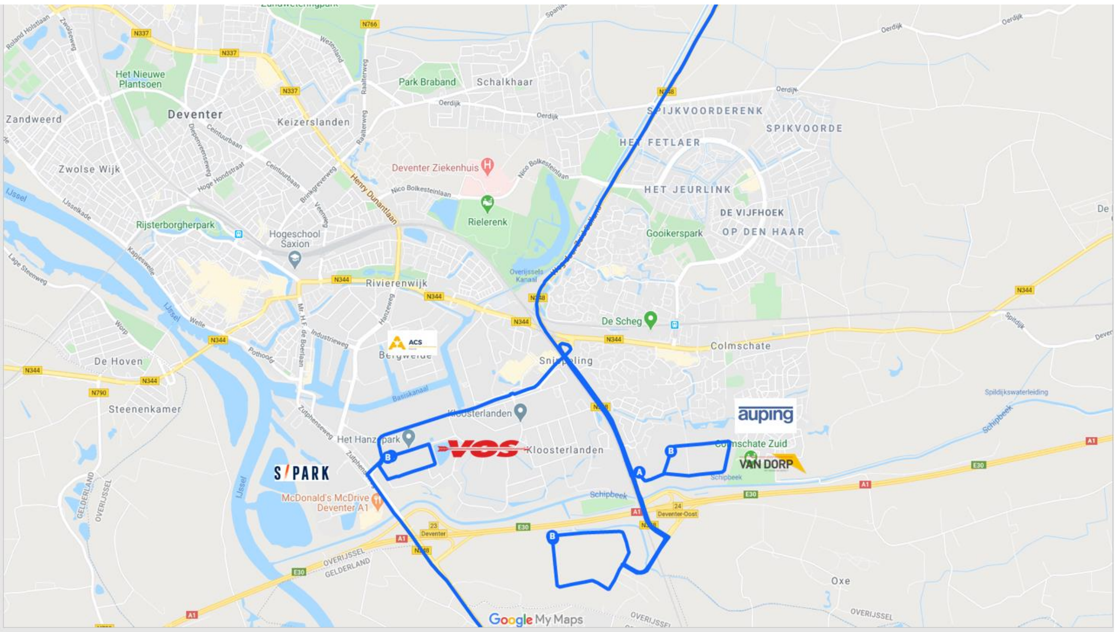
Het basisnet is een nationaal netwerk van wegen, sporen en vaarwater aangewezen voor het vervoer van gevaarlijke stoffen. In regeling basisnet is te vinden welke risico plafonds langs verschillende routes liggen.

De afbeelding hieronder geeft de basisnet specificaties weer van het basisnet voor wegtransport in Deventer.

Afbeelding 8.1 Basisnet voor wegtransport Deventer[1]



Afbeelding 8.2 Mogelijke routering wegtransport GROHW



Aangezien het transport van zuurstof en/of waterstof binnen het GROHW project op veel kleinere afstanden is gericht dan de beoogde transport wegen aangegeven in het basisnet is het basisnet in dit project niet relevant. Enkel voor de aanvoer van deze producten in geval van productie tekorten zal op het basisnet worden terug gevallen.

9 BUISLEIDINGEN

De mogelijkheid wordt onderzocht om de geproduceerde waterstof per buisleiding in plaats van met vrachtwagens naar de grootste gebruikers te transporteren. Dit zijn de gebruikers Nefit en ACS. Het voorgestelde tracé van de buisleiding (zoals weergegeven in onderstaande figuur) loopt van de productielocatie op S/park via Nefit naar ACS.

[1] https://geoservices.rijkswaterstaat.nl/ext/geoweb51/index.html?viewer=Infomil-PR

Voor de aanleg van een buisleiding voor het vervoer van gevaarlijke stoffen (waaronder waterstof) is altijd een omgevingsvergunning nodig op grond van het Besluit omgevingsrecht (Bor). Daarnaast is voor een buisleiding voor het transport van waterstof het Besluit externe veiligheid buisleidingen (Bevb) van toepassing, wanneer deze valt onder art. 2 categorie c uit de Regeling externe veiligheid buisleidingen (Revb):

- buisleidingen voor brandbare stoffen met een uitwendige diameter van 70 mm of meer of een binnendiameter van 50 mm of meer en een druk van 1.600 kPa of meer.

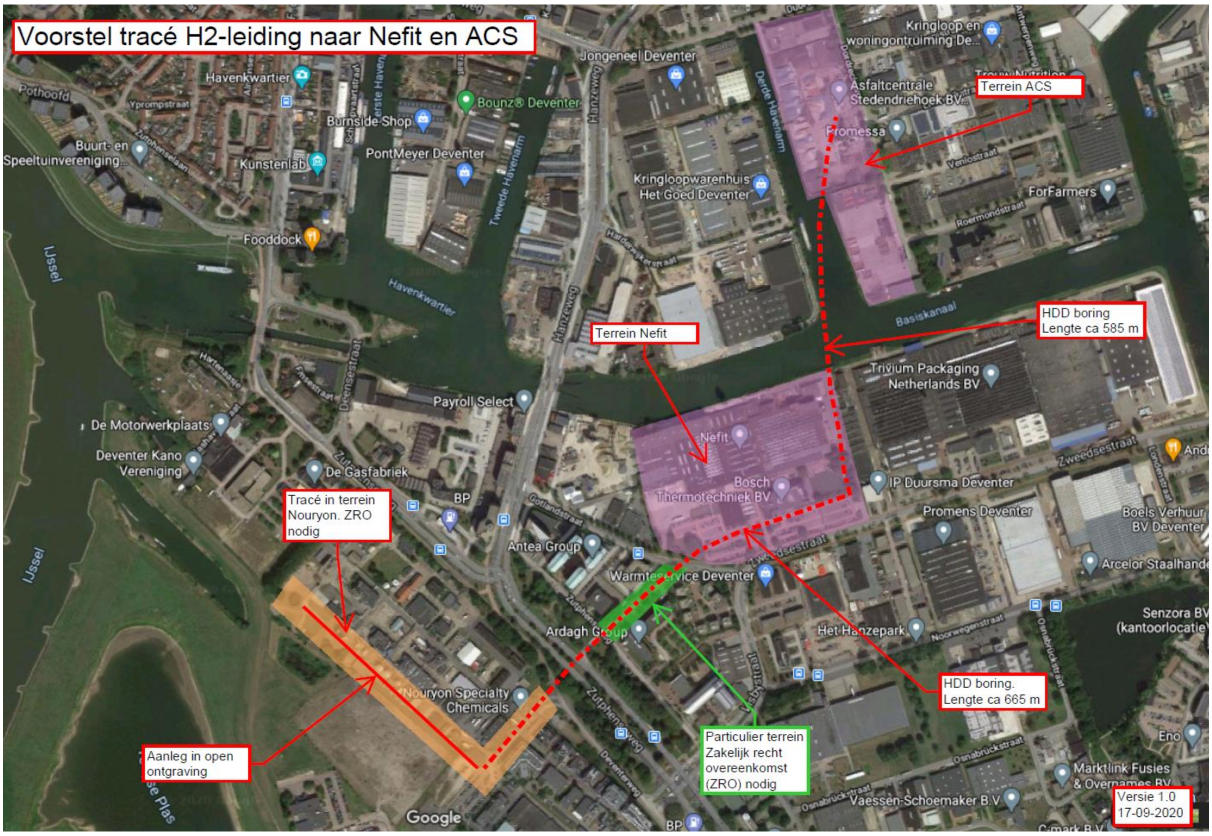
De verwachting is dat de diameter van de buisleiding groter is dan de hierboven genoemde waardes, en de buisleiding dus onder het Bevb valt.

Volgens het Bevb is de aanleg van een buisleiding alleen toegestaan indien dit in overeenstemming is met het ter plaatse geldende bestemmingsplan of er voor de aanleg een omgevingsvergunning is verleend tot afwijking van het bestemmingsplan. Aangezien er hier op een nieuw traject een buisleiding wordt aangelegd, is hiervoor waarschijnlijk een vergunning voor afwijking van het bestemmingsplan nodig.

Er is een omgevingsvergunning nodig zowel voor het oprichten van de inrichting (in dit geval de buisleiding) als voor het aanleggen van de buisleiding en eventuele wijziging van het bestemmingsplan die daarvoor nodig is. Voor de buisleiding kan dus een aparte vergunning worden aangevraagd, maar het is ook mogelijk dat de buisleiding deel gaat uitmaken van een bestaande inrichting. In dat geval moet de bestaande omgevingsvergunning voor deze inrichting worden aangepast.

Het voorgestelde traject loopt deels door particulier terrein. In dat geval is er ook een zakelijk recht overeenkomst of recht van opstal nodig om op dat terrein een leiding aan te mogen leggen.

Afbeelding 9.1 Voorgesteld tracé van buisleiding voor waterstoftransport van productielocatie naar gebruikers Nefit en ACS



10 OVERIGE VERGUNNINGEN

Naast bovenstaande vergunningen is een bouwvergunning benodigd en zijn er afhankelijk van de locatie in het bestemmingsplan mogelijk eisen gesteld aan archeologie en milieukundig (bodem) onderzoek. Deze vergunningen hebben een veel kortere proceduretijd en zijn qua complexiteit een stuk eenvoudiger. Om die reden zijn deze overige vergunningen niet uitgebreid beschreven in deze notitie.

III

APPENDIX: GENERAL POINTS OF ATTENTION CONCERNING HYDROGEN SAFETY

NOTITIE

Onderwerp	Generieke veiligheidsaandachtspunten
Project	GROHW
Opdrachtgever	-
Projectcode	119017
Status	Concept 01
Datum	12 november 2020
Referentie	-
Auteur(s)	Marieke Wingelaar
Gecontroleerd door	Fenna van de Watering
Goedgekeurd door	Fenna van de Watering
Paraaf	
Bijlage(n)	-
Aan	
Kopie	

1 INTRODUCTIE

Dit document geeft een overzicht van generieke aandachtspunten op het gebied van veiligheid die relevant zijn voor het ontwerpen van een waterstofsysteem. Binnen het GROHW project is veiligheid gedefinieerd als randvoorwaarde. Dat betekent dat bij het maken van systeemkeuzes steeds moet worden getoetst of aan de voorwaarden op het gebied van veiligheid wordt gedaan. Er bestaan echter nog niet voldoende algemeen geldende richtlijnen en regels om aan te toetsen, doordat toepassing van waterstof binnen de bebouwde omgeving nog relatief nieuw is.

Ook uit de inventarisatie van kennishiaten op het gebied van waterstof uitgevoerd in het kader van het Waterstof Veiligheid Innovatie Programma (WVIP) kwam dit als ontbrekende informatie naar voren. Het blijkt dat er vaak nog onduidelijkheid is over de risico's en effecten van waterstof in de bebouwde omgeving en dat er geen duidelijk toetsingskader is. Wanneer er wel richtlijnen, ontwerpstandaarden of veiligheidsstudies bestaan, zijn deze vaak niet algemeen toegankelijk voor alle betrokken partijen.

Bij het ontwerpen en in gebruik nemen van een waterstofsysteem zijn er verschillende aspecten van veiligheid van belang. Op het gebied van externe veiligheid (de risico's en effecten voor de omgeving), is er beleid en risiconormering voor handen. Wanneer het gaat over systeemontwerp en systeemintegriteit, of de effecten van vrijkomen van waterstof, is het echter nog onduidelijk welke risico's en effecten acceptabel zijn.
Er worden hier daarom geen algemeen geldende standaarden gegeven waaraan getoetst moet worden. Wel worden er aandachtspunten benoemd die voor elk waterstof systeem van toepassing kunnen zijn. Voor elke individuele situatie is echter maatwerk nodig.

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1.1 Waterstof en veiligheid

Waterstofopslag onder druk

Opslag van waterstof onder druk brengt risico's met zich mee. Er zijn verschillende externe factoren die bijdragen aan deze risico's:

- Externe factoren die verhoging van de druk in het drukvat veroorzaken, waardoor deze kan bezwijken. Bijvoorbeeld opwarming door een externe brand.
- Beschadiging van drukvat door externe impact.
- Corrosieve en chemisch agressieve condities leiden tot beschadiging van de omhulling.

Beschadiging kan leiden tot een lek, waaruit waterstof kan vrijkomen. Bij ontsteking ontstaat hierdoor een fakkelbrand of explosie. Ook kan het drukvat mogelijk exploderen.

Brand

Waterstofgas ontbrandt gemakkelijk. Afhankelijk van waar de lekkage zich bevindt en hoe groot deze is, kunnen heel kleine vlammen of grote fakkelbranden ontstaan. De vlam is kleurloos, maar kan zichtbaar worden gemaakt met een warmtebeeldcamera of een nevelstraal water. Door een nevelstraal kleurt de vlam oranje. Het blussen van een gasbrand kan leiden tot het ontstaan van een brandbare gaswolk wat ongewenst is.

Ontsnapping waterstofgaswolk

Waterstofgas is kleurloos en reukloos. Het vrijkomende gas kan dicht bij het lek worden gedetecteerd met een warmtebeeldcamera of via stationaire gasdetectie. Een lekkage van vloeibare waterstof verdampt vrijwel meteen

2 DE VERSCHILLENDE ASPECTEN VAN VEILIGHEID

2.1.1 Externe veiligheid

Externe veiligheid gaat over de risico's voor mens en milieu bij gebruik, opslag en vervoer van gevaarlijke stoffen. Het gaat hier specifiek om de risico's voor de omgeving als gevolg van een incident met gevaarlijke stoffen veroorzaakt bij een inrichting, buisleiding of transportroute.

2.1.2 Explosieveiligheid (ATEX)

ATEX (ATmosphère EXplosible) is het synoniem voor twee Europese richtlijnen op het gebied van explosiegevaar:

- De ATEX richtlijn 114 (2014/34/EU en voorheen ATEX 95) heeft betrekking op de technische integriteit en bevat normen voor apparatuur en beveiligingssystemen die worden gebruikt in explosiegevaarlijke omgevingen. Deze richtlijn is vooral van toepassing op fabrikanten.
- De ATEX richtlijn 153 (1999/92/EG en voorheen ATEX 137) beschrijft de veiligheidseisen waaraan werkgevers moeten voldoen om een veilige werkomgeving te creëren voor werkomgevingen waarin explosieve atmosferen kunnen voorkomen.

In Nederland zijn deze eisen geïmplementeerd in het Warenwetbesluit explosieveilig materieel 2016 en in het Arbeidsomstandighedenbesluit.

2.1.3 Arboveiligheid

Arboveiligheid gaat over het garanderen van een veilige werkomgeving voor werknemers. Voor waterstof zijn de eisen en verplichtingen van belang op het gebied van explosieveiligheid. Verplichtingen die voortkomen uit het Arbeidsomstandighedenbesluit:
- het beoordelen van explosierisico's (risico-inventarisatie en -evaluatie);
- het indelen van gebieden waar explosieve atmosferen kunnen voorkomen in gevarenzones;
- het nemen van zowel technische als organisatorische maatregelen in gevarenzones;
- het informeren van medewerkers;
- het vastleggen van bovenstaande in een explosieveiligheidsdocument

De hierboven genoemde indeling in gevarenzones bepaalt welk materiaal er gebruikt mag worden. Dit is vastgelegd in het Warenwetbesluit explosieveilig materieel 2016.

2.1.4 Procesveiligheid (systeemveiligheid)

Bij procesveiligheid worden veiligheidsrisico's van het omgaan met gevaarlijke stoffen in procesinstallaties (inclusief opslagtanks) geëvalueerd. Het gaat om het voorkomen van het onbedoeld of ongecontroleerd vrijkomen van gevaarlijke stoffen ('loss of containment') en het optreden van de gevolgen daarvan zoals brand, explosie of een toxische emissie. Hierbij staan het ontwerp, de technische integriteit en de beveiliging van de procesinstallatie centraal. Voorbeelden van deelgebieden binnen procesveiligheid zijn:
- Systeemontwerp (componenten, materiaalkeuze en -dikte, materiaal integriteit, druksystemen)
- Veiligheidsmechanismen
- Onderhoud
- Keuringen
- Risicoanalyses en risicomanagement (HAZOP, LOPA)

Warenwetgeving (drukapparatuur)
Constructie
Een waterstofinstallatie is drukapparatuur. In het Warenwetbesluit drukapparatuur 2016 zijn eisen vastgelegd aan het op de markt aanbieden en in bedrijf stellen, het gebruiken en nadien wijzigen van drukapparatuur. Daarnaast zijn op het in de handel brengen van drukapparatuur zijn Europese productrichtlijnen van toepassing. De ontwerpeisen voor een waterstofinstallatie liggen vast in de Europese richtlijn drukapparatuur (PED). De fabrikant heeft de plicht om bij het ontwerp van drukapparatuur en samenstellen een analyse te maken van de risico's en gevaren die bestaan ten gevolge van de druk. Bij het ontwerp en de bouw van drukapparatuur of het samenstel moet hij vervolgens rekening houden met deze risicoanalyse.

De eisen waaraan de waterstofinstallatie moet voldoen zijn vastgelegd in bijlage I bij de Europese richtlijn drukapparatuur (PED). Samengevat, betekent dit in elk geval dat:
- de waterstofinstallatie voldoende sterk is om de belastingen die kunnen worden verwacht (kracht, brand, hogedruk, enz.) te weerstaan
- maatregelen zijn genomen om de waterstofinstallatie veilig te bedienen
- de waterstofinstallatie zodanig is ontworpen dat deze veilig kan worden geïnspecteerd
- de waterstofinstallatie veilig kan worden gevuld en geleegd;
- passende beveiligingen (zoals drukontlastkleppen of veerveiligheden) zijn aangebracht om in te grijpen als de druk ontoelaatbaar stijgt. Als een beveiliging wordt aangesproken, moet deze afblazen op een zodanige plaats dat daarbij geen gevaar voor personen kan optreden.

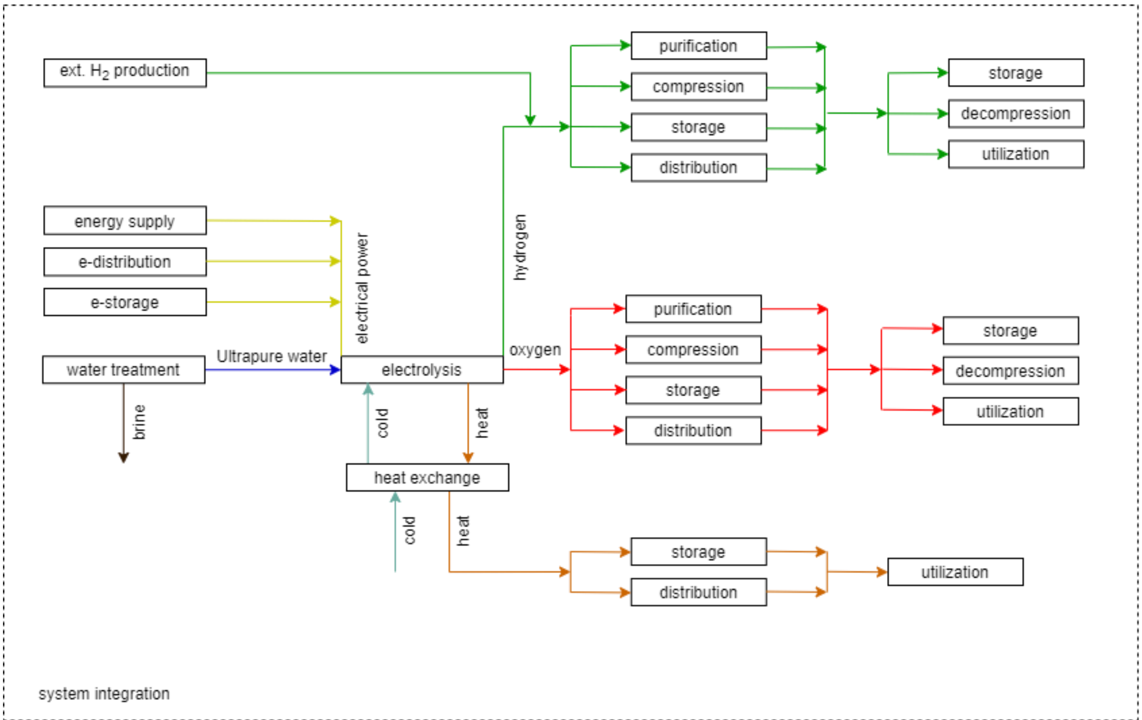
Om aan de eisen te voldoen wordt meestal een geharmoniseerde norm toegepast (ISO, NEN). Dit is niet verplicht, maar als er geen geharmoniseerde norm wordt toegepast, moet de fabrikant aantonen dat de waterstofinstallatie wel voldoet aan het PED.

Gebruik
De wet (het Warenwetbesluit drukapparatuur 2016) stelt niet alleen eisen aan het in de handel brengen van drukapparatuur, maar ook aan de ingebruikneming en het gebruik van drukapparatuur. De gebruiker moet de waterstofinstallatie laten keuren voordat deze in gebruik wordt genomen, bij wijzigingen of reparaties en verder zo vaak als nodig is. Het Warenwetbesluit drukapparatuur is verder uitgewerkt in de Warenwetregeling drukapparatuur. Hierin staat wie de verplichte keuringen moet uitvoeren. In deze regeling is drukapparatuur 'aangewezen' die in de risicocategorie valt die moet worden gekeurd door een NL-conformiteitsbeoordelingsinstantie (NL-CBI). Voor waterstofinstallaties geldt dat drukvaten worden 'aangewezen' als de waarde P x V voor het drukvat boven een bepaalde waarde komt. Aangewezen drukvaten moeten worden gekeurd voordat deze in gebruik mogen worden genomen en vervolgens elke vier jaar.

3 AANDACHTSPUNTEN PER DEELSYSTEEM

Het waterstofsysteem kan verdeeld worden in de volgende deelsystemen:
- Productie;
- Compressie;
- Opslag;
- Transport;
- Gebruik.

In de volgende paragrafen worden per deelsysteem de relevante de generieke aandachtspunten beschreven.



4 PRODUCTIE

4.1 BRZO en Bevi

Het Besluit risico's zware ongevallen (BRZO) en het Besluit externe veiligheid inrichtingen (Bevi) zijn van toepassing op inrichtingen waarin gevaarlijke stoffen voorkomen. De productie van waterstof maakt mogelijk onderdeel uit van een inrichting waarop het BRZO en Bevi van toepassing zijn. Zie voor verdere toelichting paragraaf 6 Opslag.

4.2 Richtlijnen en normen

Warenwetbesluit drukapparatuur 2016 en Europese richtlijn drukapparatuur (PED)
In het Warenwetbesluit drukapparatuur 2016 zijn eisen vastgelegd aan het op de markt aanbieden en in bedrijf stellen, het gebruiken en nadien wijzigen van drukapparatuur. Hier vallen ook waterstofinstallaties onder.

Warenwetbesluit explosieveilig materieel 2016
Beschrijft de eisen aan apparatuur en beveiligingen op plekken waar mogelijk een explosieve atmosfeer voorkomt.

Overige normen en standaarden
- NEN-ISO 22734:2019 en - Waterstofgeneratoren gebruikmakend van water elektrolyse - Industriële, commerciële en binnenshuis toepassingen. (https://www.nen.nl/NEN-Shop/Norm/NENISO-227342019-en.html)
- ISO/TR 15916:2015 - Basic considerations for the safety of hydrogen systems (https://www.iso.org/standard/56546.html)

5 COMPRESSIE

5.1 BRZO en Bevi

Het Besluit risico's zware ongevallen (BRZO) en het Besluit externe veiligheid inrichtingen (Bevi) zijn van toepassing op inrichtingen. De compressie van waterstof maakt mogelijk onderdeel uit van een inrichting waarop het BRZO en Bevi van toepassing zijn. Zie voor verdere toelichting paragraaf 4 Opslag.

5.2 Richtlijnen en normen

Warenwetbesluit drukapparatuur 2016 en Europese richtlijn drukapparatuur (PED)
In het Warenwetbesluit drukapparatuur 2016 zijn eisen vastgelegd aan het op de markt aanbieden en in bedrijf stellen, het gebruiken en nadien wijzigen van drukapparatuur. Hier vallen ook waterstofinstallaties onder.

Warenwetbesluit explosieveilig materieel 2016
Beschrijft de eisen aan apparatuur en beveiligingen op plekken waar mogelijk een explosieve atmosfeer voorkomt.

Normen en standaarden
- ISO/TR 15916:2015 - Basic considerations for the safety of hydrogen systems (https://www.iso.org/standard/56546.html)
- NEN-EN 1012-3:2013 en - Compressoren en vacuümpompen - Veiligheidseisen - Deel 3: Procescompres-soren (https://www.nen.nl/nen-en-1012-3-2013-en-189768)

6 OPSLAG

6.1 BRZO

De hoeveelheid en de aard van de gevaarlijke stoffen die in een inrichting aanwezig zijn, bepaalt welke eisen volgens de wet aan de inrichting worden gesteld. Wanneer de hoeveelheid gevaarlijke stoffen boven de drempelwaardes uit het BRZO komt, moet de inrichting aan de hierin gestelde verplichtingen voldoen. Ook hier moet rekening mee worden gehouden bij het systeemontwerp en de locatiekeuze, omdat BRZO inrichtingen niet op elke locatie zijn toegestaan, afhankelijk van de regels van het bestemmingsplan.

Het Besluit risico's zware ongevallen (BRZO) is de Nederlandse implementatie van de Europese Seveso III richtlijn. Het doel van deze richtlijn is de preventie van zware ongevallen bij inrichtingen waar grote hoeveelheden gevaarlijke stoffen aanwezig zijn, en het beperken van de gevolgen wanneer zo'n ongeval zich toch voordoet. In het BRZO wordt onderscheid gemaakt tussen twee type inrichtingen: lagedrempelinrichtingen of hogedrempelinrichtingen, afhankelijk van de hoeveelheid gevaarlijke stoffen die er aanwezig is. De veiligheidseisen die aan bedrijven worden gesteld zijn afhankelijk van het type inrichting. De BRZO drempelwaardes voor waterstof en zuurstof zijn weergegeven in Tabel 6.1. Het gaat hierbij om vergunde hoeveelheid, niet om daadwerkelijke hoeveelheid die op een bepaald moment in de inrichting aanwezig is

Tabel 6.1 Drempelwaardes BRZO 2015

gevaarlijke stof	Lage drempelwaarde (ton)	Hoge drempelwaarde (ton)
waterstof	5	50
zuurstof	200	2000

Eisen die aan BRZO-inrichtingen gesteld worden:
- Lagedrempelinrichting (inrichting die alleen de lage drempelwaarde overschrijdt).
  Deze inrichting moet alle maatregelen treffen die nodig zijn om zware ongevallen te voorkomen en de gevolgen daarvan voor mens en milieu te beperken. Daarnaast moet het bedrijf een Preventiebeleid Zware Ongevallen opstellen en voor de uitvoering en bepaling daarvan een veiligheidsbeheerssysteem implementeren. Ook vinden er jaarlijks BRZO inspecties door de overheid plaats.
- Hogedrempelinrichting (inrichting die ook de hoge drempelwaarde overschrijdt).
  Deze inrichting moet, naast de verplichtingen voor de lagedrempelinrichtingen, een veiligheidsrapport indienen, waarmee wordt aangetoond dat de preventie en de beheersing van de gevaren van zware ongevallen in orde zijn. Daarnaast moet er ook een intern noodplan worden opgesteld voor zware ongevallen binnen het bedrijf.

Preventiebeleid Zware Ongevallen (PBZO) en veiligheidsbeheerssysteem
BRZO inrichtingen moeten een preventiebeleid opstellen voor het voorkomen van zware ongevallen. Dit wordt vastgelegd in het PBZO document. Het preventiebeleid moet worden uitgevoerd met een veiligheidsbeheerssysteem. Het veiligheidsbeheerssysteem moet voldoen aan de elementen genoemd in bijlage III van de Seveso III richtlijn. Het veiligheidsbeheerssysteem is afgestemd op de gevaren, de industriële werkzaamheden en de complexiteit van de organisatie.

6.2 Bevi

Het doel van het Besluit externe veiligheid inrichtingen (Bevi) is om mensen in de buurt van een bedrijf met gevaarlijke stoffen te beschermen. In het Bevi staat de verplichting om veiligheidsafstanden aan te houden tussen gevoelige objecten en risicovolle bedrijven. Voor sommige inrichtingen zijn in het Bevi vaste veiligheidsafstanden vastgelegd (dit zijn de categoriale inrichtingen), terwijl voor andere risicocontouren moeten worden berekend met de rekenmethodiek Bevi (software Safeti-NL en 'handleiding risicoberekeningen Bevi) (voor niet-categoriale inrichtingen). Gemeenten en provincies hanteren de normen uit het besluit bij het opstellen en wijzigen van bestemmingsplannen en bij het verlenen van omgevingsvergunningen.

Een inrichting valt onder andere onder het Bevi indien:
- Meer dan 150 m^3 licht ontvlambare vloeistof of zeer licht ontvlambare vloeistof aanwezig is in een bovengronds insluitsysteem;
- Inrichtingen waar propaan aanwezig is in een insluitsysteem met een inhoud van:[1]
  - meer dan 13 m^3 propaan en ten hoogste 50 m^3 en met een jaarlijkse doorzet van meer dan 600 m^3
  - meer dan 50 m^3
- Inrichtingen waarop het Brzo van toepassing is.

QRA
QRA (kwantitatieve risico analyse) is een methode om het groepsrisico en plaatsgebonden risico (zie hieronder) uit te rekenen. De rekenmethodiek Bevi is verplicht voor Bevi inrichtingen en is vastgelegd in het Revi. Het invloedsgebied is het gebied dat relevant is voor de berekening van het groepsrisico. Het invloedsgebied voor inrichtingen waar een QRA voor opgesteld moet worden, wordt begrensd door de 1%-letaliteitgrens

Plaatsgebonden risico
In artikel 1 van het Besluit externe veiligheid inrichtingen is een definitie opgenomen van het plaatsgebonden risico (PR). Het PR is het risico (uitgedrukt in kans per jaar) dat één persoon die zich onafgebroken en onbeschermd op die plaats bevindt, overlijdt als rechtstreeks gevolg van een calamiteit met een gevaarlijke stof. In het besluit is een norm opgenomen voor het plaatsgebonden risico. Deze norm is een grenswaarde voor kwetsbare objecten en moet daarom door het bevoegde gezag in acht worden genomen (mag niet van worden afgeweken).

Het plaatsgebonden risicocontour 10^{-6}/jr geldt als richtwaarde voor beperkt kwetsbare objecten en als grenswaarde voor kwetsbare objecten. Dit betekent dat kwetsbare objecten niet binnen deze contour aanwezig mogen zijn of mogen komen. Beperkt kwetsbare objecten zijn alleen toegestaan als daarvoor voldoende motivatie is gegeven.

Groepsrisico
De grens van het invloedsgebied van een inrichting is 1% letaliteit. Met groepsrisico wordt de cumulatieve kansen per jaar dat ten minste 10, 100 of 1000 personen overlijden als rechtstreeks gevolg van hun aanwezigheid in het invloedsgebied van een inrichting en een ongewoon voorval binnen die inrichting waarbij een gevaarlijke stof betrokken is bedoeld. Hierbij kan sprake zijn van een 'uitgebreide' of een 'beperkte' verantwoordingsplicht. Bij de uitgebreide variant gelden alle elementen zoals die bij de verantwoordingsplicht in het Bevi worden genoemd. Bij de beperkte variant wordt enkel ingegaan op de hoogte van het groepsrisico, mogelijkheden tot voorbereiding van bestrijding en beperking van een ramp en de mogelijkheden tot zelfredzaamheid.

Oprichten van een Bevi-inrichting
Vaak is er voor het oprichten van een Bevi inrichting een afwijking van het bestemmingsplan nodig. Daarnaast moet voor Bevi inrichtingen het plaatsgebonden risico worden berekend en het groepsrisico worden verantwoord. Een omgevingsvergunning voor een Bevi-inrichting kan alleen verleend worden

[1] Dit kan als waterstof kunnen worden uitgelegd.

wanneer aan deze eisen wordt voldaan. Hier moet bij het ontwerp van de inrichting rekening mee worden gehouden. De volgende aspecten zijn bepalend voor de hoogte van het plaatsgebonden risico en het groepsrisico:

- De jaarlijkse kans dat zich een ongeval voordoet met gevaarlijke stoffen. Deze grootheid is op zichzelf weer afhankelijk van:
  - De opslag methode,
  - de aard en omvang van de gevaarlijke stoffen,
  - de daarmee verrichte handelingen,
  - de wijze waarop een inrichting omgaat met veiligheid.
- Het aantal potentiële dodelijke slachtoffers in de omgeving van de activiteit. Dit hangt af van:
  - de samenstelling (hoeveelheid én spreiding) van de bevolking,
  - de effecten van een stof in geval van een ongeluk,
  - de mogelijkheden tot zelfredzaamheid en bestrijding van de gevolgen.

6.3 Opslag in afgesloten ruimte vs. open lucht

Wanneer waterstof vrijkomt in de open lucht, zal het snel stijgen en zich verdunnen met de lucht verdunnen. Hierdoor is er minder kans op het ophopen van waterstof tot gevaarlijke concentraties Een waterstofinstallatie in de open lucht heeft daardoor de voorkeur. Wanneer waterstof echter in een afgesloten ruimte wordt opgeslagen, zoals binnen een gebouw of in containers (wat vaak voorkomt), kan waterstof zich bij het vrijkomen wel in de ruimte ophopen. Hierdoor ontstaat gemakkelijker een explosieve atmosfeer. Indien toch voor een gesloten ruimte wordt gekozen, is het belangrijk te zorgen voor voldoende ventilatie. Ook moet er rekening mee worden gehouden dat bij het modelleren van de waterstof installatie in bijvoorbeeld Safeti-NL er niet altijd goed binnen een gebouw kan worden gemodelleerd.

6.4 Richtlijnen en normen

Warenwetbesluit drukapparatuur 2016 en Europese richtlijn drukapparatuur (PED)

In het Warenwetbesluit drukapparatuur 2016 zijn eisen vastgelegd aan het op de markt aanbieden en in bedrijf stellen, het gebruiken en nadien wijzigen van drukapparatuur. Hier vallen ook waterstofinstallaties onder.

Warenwetbesluit explosieveilig materieel 2016

Beschrijft de eisen aan apparatuur en beveiligingen op plekken waar mogelijk een explosieve atmosfeer voorkomt.

PGS 35

De PGS (Publicatiereeks Gevaarlijke Stoffen) 35 is een richtlijn voor de arbeidsveilige, milieuveilige en brandveilige toepassing van installaties voor het afleveren van waterstof aan voertuigen en werktuigen. PGS 35 is gericht op waterstof tankstations, maar de veiligheidseisen kunnen ook van toepassing zijn op de opslag van waterstof. (Aandachtspunt hierbij is dat het niet altijd duidelijk is welk van deze eisen ook gelden voor andere toepassingen).

In PGS 35 staan veiligheidseisen waaraan de waterstofinstallatie moet voldoen. Dit heeft onder andere betrekking op:

- Basisveiligheid
- Constructie en installatie
- Compressors
- Opslagtanks voor waterstof
- Vullen van de opslagtank
- Afblaasvoorzieningen
- Bewaken en monitoren
- Terreininrichting

- Toegankelijkheid voor calamiteiten
- Interne veiligheidsafstanden

Normen en standaarden
- ISO/TR 15916:2015 - Basic considerations for the safety of hydrogen systems (https://www.iso.org/standard/56546.html)

7 TRANSPORT

7.1 Buisleiding

De kans op ongevallen met gevaarlijke stoffen is bij transport via buisleidingen over het algemeen kleiner dan bij transport over de weg. Voor de aanleg van een buisleiding voor het vervoer van gevaarlijke stoffen (waaronder waterstof) is altijd een omgevingsvergunning nodig op grond van het Besluit omgevingsrecht (Bor). Daarnaast is voor een buisleiding voor het transport van waterstof het Besluit externe veiligheid buisleidingen (Bevb) van toepassing, wanneer deze valt onder art. 2 categorie c uit de Regeling externe veiligheid buisleidingen (Revb):
- buisleidingen voor brandbare stoffen met een uitwendige diameter van 70 mm of meer of een binnendiameter van 50 mm of meer en een druk van 1.600 kPa of meer

Voor buisleidingen die onder het Bevb vallen moet net als voor Bevi inrichtingen het groepsrisico berekend worden en het plaatsgebonden risico worden verantwoord. Deze zijn afhankelijk van de eigenschappen van de leiding. Daarnaast is volgens het Bevb de aanleg van een buisleiding alleen toegestaan indien dit in overeenstemming is met het ter plaatse geldende bestemmingsplan, of er voor de aanleg een omgevingsvergunning is verleend tot afwijking van het bestemmingsplan. In het geval dat de leiding door particulier terrein loopt, is er ook een zakelijk recht overeenkomst of recht van opstal nodig om op dat terrein een leiding aan te mogen leggen.

Factoren waar bij het ontwerp rekening mee gehouden moet worden zijn dus:
- Dikte van de leiding
- Materiaal
- Druk
- Leidingtracé
- Bovengronds of ondergronds (en diepte)
- Beheersmaatregelen

7.2 Weg (tubetrailers)

Het risico van transport over de weg wordt bepaald door de inhoud en de druk van de tubetrailer. Daarnaast hebben ook de lengte van de route, de frequentie van het transport en het type weg invloed op de risico's.

7.2.1 Wetgeving

ADR
In het ADR (Accord européen relatif au transport international des marchandises Dangereuses par Route) zijn regels vastgelegd voor het vervoer van gevaarlijke stoffen. Dit is een Europese regeling, die in Nederland wettelijk is verankerd via de Wet Vervoer Gevaarlijke Stoffen. Waterstof is ingedeeld in ADR klasse II.

Basisnet
Het Basisnet is een netwerk van hoofdroutes over rijkswegen, het spoor en binnenwateren waarover het vervoer van gevaarlijke stoffen plaats mag vinden. In de Regeling Basisnet staan de risicoplafonds voor het Basisnet.

7.2.2 Laden en lossen

Ook het laden en lossen van waterstof brengt risico's met zich mee. In het geval waterstof wordt overgebracht van de tubetrailer naar een andere opslag, of van de opslag naar de tubetrailer, zijn de leidingdiameters, druk en frequentie van het verladen bepalend voor het risico voor de omgeving. Daarnaast wordt het risico bepaald door de procedurele, bouwkundige en technische voorzieningen (bijvoorbeeld aanrijbeveiligingen, noodprocedures) die aanwezig zijn om een ongeval te voorkomen of te beperken. Voor het laden en lossen van waterstof tubetrailers veiligheidsrichtlijnen en procedures opgesteld, zoals in PGS 35. Wanneer het laden en lossen plaatsvindt bij een Bevi inrichting, moeten de risico's met een QRA bepaald worden.

7.3 Richtlijnen en normen

Warenwetbesluit drukapparatuur 2016 en Europese richtlijn drukapparatuur (PED)
In het Warenwetbesluit drukapparatuur 2016 zijn eisen vastgelegd aan het op de markt aanbieden en in bedrijf stellen, het gebruiken en nadien wijzigen van drukapparatuur. Hier vallen ook waterstofinstallaties onder.

8 GEBRUIK

De veiligheidseisen hangen af van de toepassing. Voor waterstoftankstations is in elk geval PGS35 van toepassing.

9 OVERZICHT

De hierboven beschreven veiligheidsaandachtspunten worden hieronder samengevat per activiteit (Tabel 1) en per fase in het project, toepasbaar voor elk project voor de ontwikkeling van een waterstofinstallatie (Tabel 2).

Tabel 1 Overzicht van welke veiligheidsaandachtspunten relevant zijn voor de verschillende activiteiten

	Productie	Compressie	Opslag	Transport	Gebruik
BRZO	x	x	x		
Bevi	x	x	x		
Bevb				x	
PGS					x
Arbo-wetgeving (ATEX)	x	x	x	x	x
Warenwetbesluit Drukapparatuur (ATEX), Europese richtlijn drukapparatuur (PED),	x	x	x	x	x
Richtlijnen en normen (NEN en ISO)	x	x	x	x	x
Procesveiligheid	x	x	x	x	x
ADR				x	
Basisnet				x	

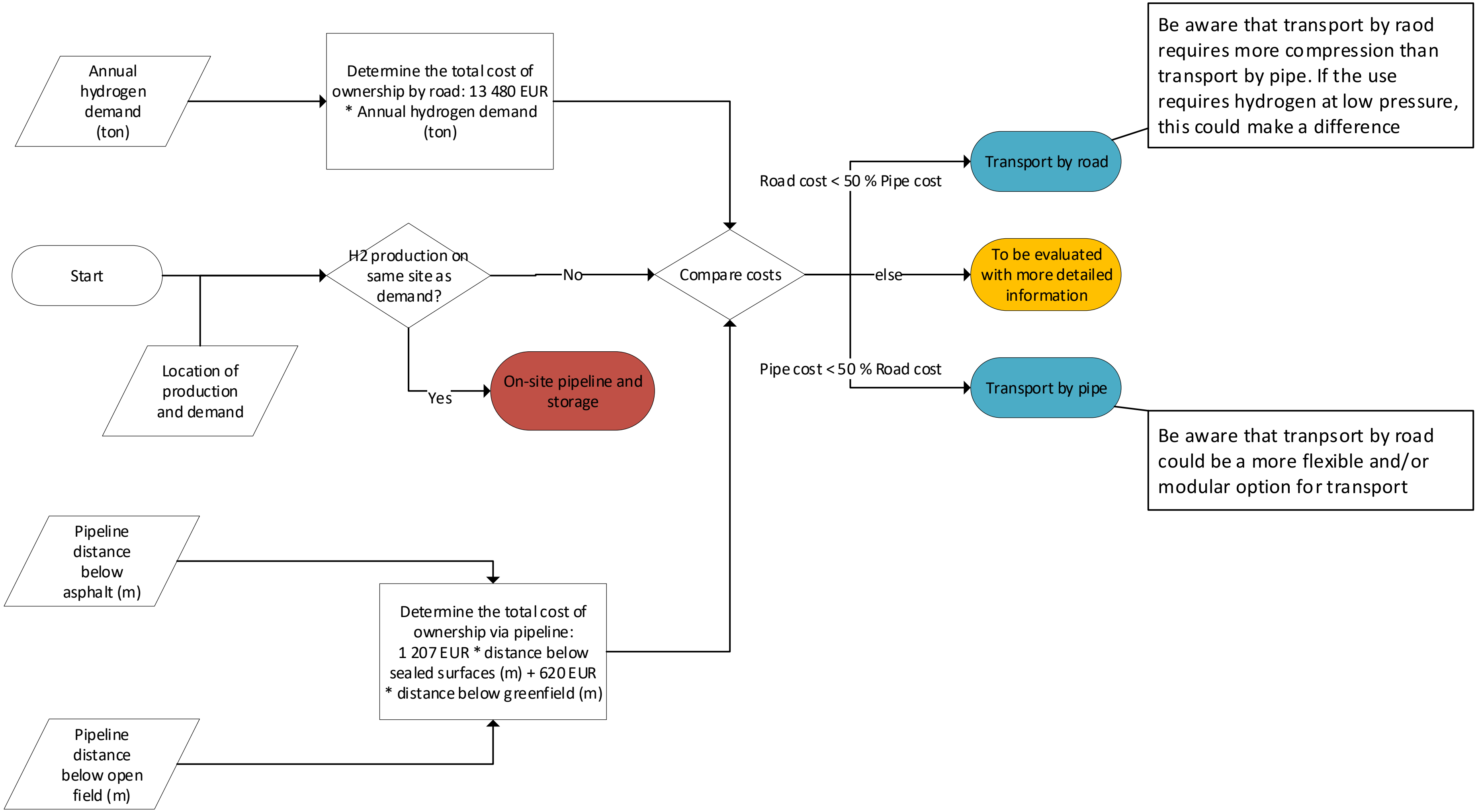
Tabel 2 Overzicht van welke veiligheidsaandachtspunten relevant zijn tijdens de verschillende fases van de ontwikkeling en ingebruikname van een waterstofsysteem

	Systeem-verkenning	Systeem ontwerp	Technisch ontwerp	Realisatie	Gebruik
BRZO	x	x		x	x
Bevi	x	x			
Bevb	x	x			
PGS			x	x	x
Arbo-wetgeving (ATEX)				x	x
Warenwetbesluit Drukapparatuur (ATEX), Europese richtlijn drukapparatuur (PED),			x	x	x
Richtlijnen en normen (NEN en ISO)			x	x	
Procesveiligheid		x	x	x	x
ADR			x		x
Basisnet			x		x

IV

APPENDIX: DECISION TREES

Decision tree – Hydrogen transport



Witteveen+Bos

REPORTING FORM OF DECISION TREE

CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s):	Samuel Schöffer
Quality controller(s):	Mascha Smith

Decision tree information (short)

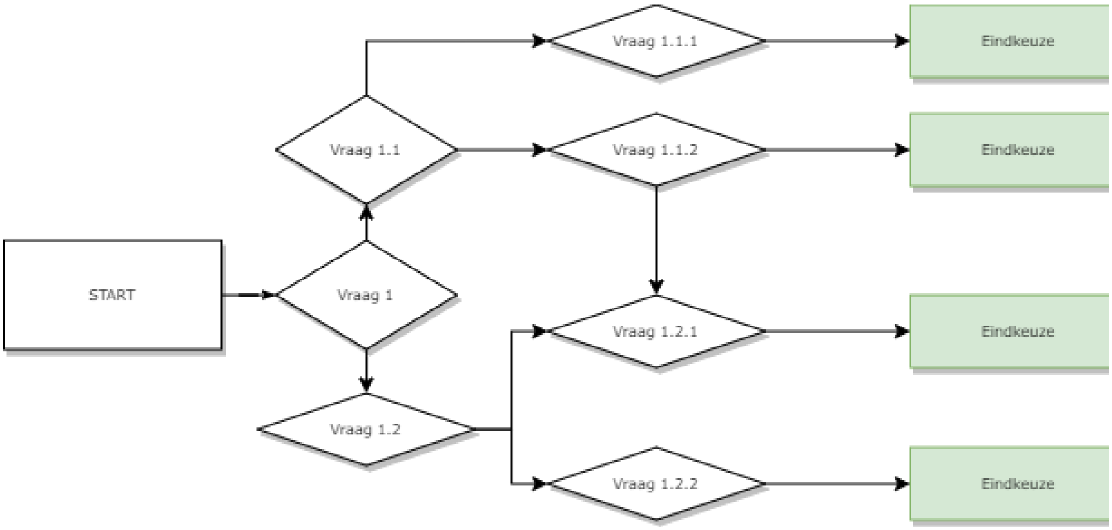
decision tree name	**Hydrogen transport method**
decision tree description (short)	**This tree decides per customer if hydrogen is transported by road or pipeline**

Quality check

Subject	Check step	Conclusion
1. Title	Does the title describe the decision tree correctly?	☒ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☐ Yes It's purely a cost-based consideration.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Formulation	Is the step formulated clearly?	☐ Yes Steps are clear.
7. Distinctiveness	Does the step produce a different results with different input data (perspectives and different trees)?	☐ Yes No, it's purely a cost-based consideration.
8. Order of steps	Is the order of the steps logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization steps of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: Click or tap here to enter text.

What are the results of the decision tree?	**Which transport method should be chosen per customer. If the difference in costs is too small, the decision will be made at a later stage.**
Which steps are in the decision tree?	1. H2 production on the same site as demand? 2. Determine the total cost of ownership by road: 13 480 EUR * Annual hydrogen demand (tonnes) 3. Determine the total cost of ownership via pipeline: 1712 EUR * distance below sealed surfaces (m) + 880 EUR * distance below greenfield (m) 4. Compare costs



Reasoning behind the steps

Answer the following questions for each of the above (sub)steps:
- What is the number of the step, and what is the step?
- Why is this step relevant?
- Which assumptions are used for the steps and its answers?
- Is the step in the right place in the tree (order of filtering)?
- Is the step distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the steps?
- What dependencies are there, and how are the dependencies processed?

Step 1: H2 production on the same site as demand?
- The step is relevant to determine whether transport is needed.
- No assumptions needed
- It's in the right place
- Input depends only on production location and location of demand.
- These are all possible results of the step.
- Dependency on location. This is determined in the scenario.

Step 2: Determine the total cost of ownership by road: 13 480 EUR * Annual hydrogen demand (tonnes)
- The step is relevant because a comparison between two transport methods is made on the basis of costs;
- Assumptions:
  - Only operational costs are relevant;
  - The lifetime of the project is 10 years;
  - The annual discount rate is 3%;
  - One delivery of hydrogen is 200 kg, regardless of pressure;
  - One delivery takes three hours, including loading, unloading, travel to and from the starting point of the truck, and travel between the production and drop-off location;
  - The total travel distance is 150 km, regardless of the distance between the production and demand location. We assume that the distance between the hydrogen hub and the starting point of the trucks is much greater than the distances within the hydrogen hub;
  - The cost for the driver is EUR 35 per hour;
  - The cost of the truck is EUR 50 per hour;
  - The truck uses 30 L of diesel per 100 km;
  - Diesel costs EUR 1,356 per L.
- The step is in the right place;
- The step is not distinctive from different perspectives. At this stage, we cannot estimate whether:
  - Road delivery is more sustainable than through a pipeline. Road delivery leads to CO_2emissions in use. Delivery via a pipe leads to CO_2emissions during construction.
  - Road delivery provides more security of supply than delivery through a pipeline. A pipeline seems more certain, but it will cause many more problems if it fails.
- The cost depends very much on the assumptions. A follow-up step applies a margin of uncertainty. Only one answer is possible for this step.
- The costs depend on the total hydrogen demand per year; this is clearly indicated.

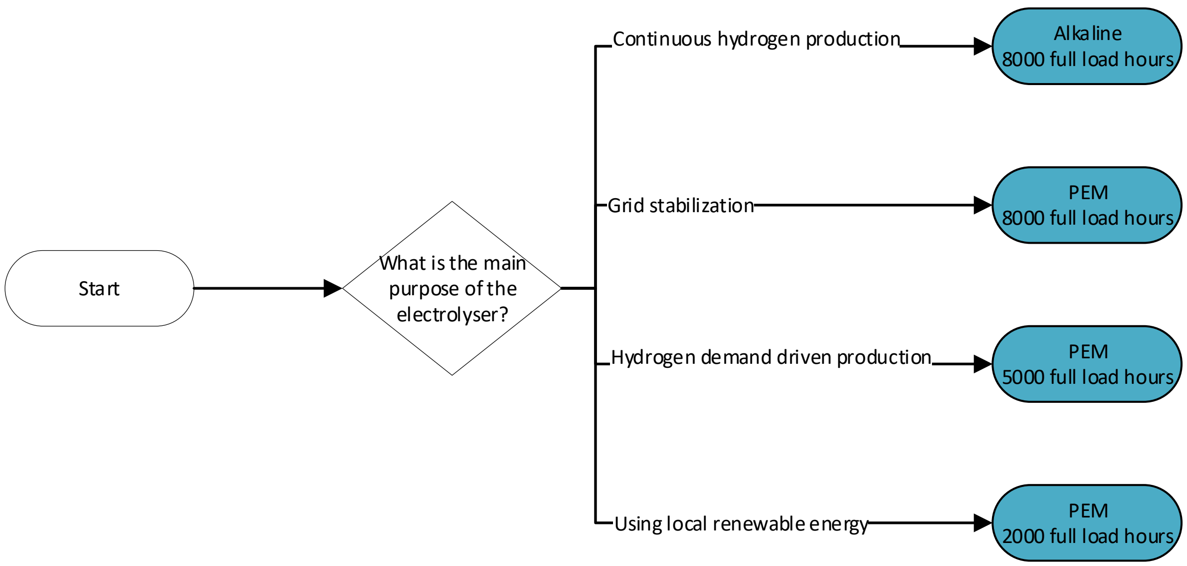
Step 3: Determine the total cost of ownership via pipeline: 1207 EUR * distance below sealed surfaces (m) + 620 EUR * distance below greenfield (m)
- The step is relevant because a comparison between two transport methods is made on the basis of cost;
- Assumptions:
  - Only investment costs are relevant;
  - The lifetime of the pipe is 50 years (supplier specification) and the lifetime of the project is 10 years. Therefore we assume the following:
    - The value of the pipeline decreases linearly over time;
    - After 10 years, the pipeline can be sold for 50% of its value;
    - This means that 40% of the investments costs is returned after 10 years;
    - An annual discount rate of 3% is applied.
  - It's a DN100 pipeline;
  - The costs for a normal steel pipeline of this diameter are based on expert judgement at:
    - EUR 1300 per meter of construction costs below sealed surfaces;
    - EUR 650 per meter of construction costs below non-sealed surfaces;
  - The cost specific to a hydrogen pipeline:
    - EUR 100 per meter of material costs;
    - Construction a hydrogen pipeline is 20% cheaper than a steel pipeline. This is because a hydrogen pipeline is made of plastic and is, therefore, easier to construct. For example, it can be delivered to much larger roles;
    - These specific costs are based on conversations we had with a hydrogen pipeline manufacturer;
  - On top of these costs, an additional 60% is charged for indirect construction costs and uncertainty;
- The step is in the right place;
- The step is not distinctive from different perspectives. At this stage, we cannot estimate whether:
  - Road delivery is more sustainable than through a pipeline. Road delivery leads to CO_2 emissions in use. Delivery via a pipe leads to CO_2 emissions during construction.
  - Road delivery provides more security of supply than delivery through a pipeline. A pipeline seems more certain, but it will cause many more problems if it fails.
- The cost depends very much on the assumptions. A follow-up step applies a margin of uncertainty. Only one answer is possible for this step.
  - The costs depend on the distance under pavement (asphalt) and open field (greenfield);

Step 4: Compare costs

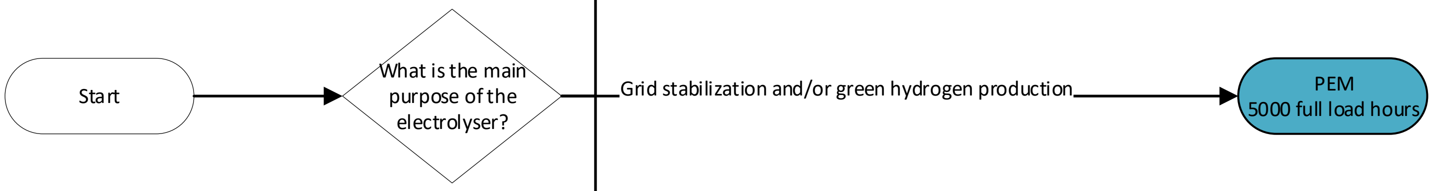
- The step is relevant because it produces the final result;
- Assumptions:
  - An option is chosen if the cost is less than half of the alternative. This is done to take into account the uncertainty in the assumptions;
  - In other cases, if the difference is smaller, there is insufficient information at this stage to make a choice. Both options are then still open.
- The step is in the right place;
- The step is not distinctive from different perspectives. At this stage, we cannot estimate whether:
  - Road delivery is more sustainable than through a pipeline. Road delivery leads to CO_2emissions in use. Delivery via a pipe leads to CO_2emissions during construction.
  - Road delivery provides more security of supply than delivery through a pipeline. A pipeline seems more certain, but it will cause many more problems if it fails.
- The step gives all possible answers, partly because one of the possible outcomes is that the step cannot yet be answered.
- The step depends on the result of steps 2 and 3.

	which data	**from/for which decision tree?**
Input data	Amount of hydrogen per year	Scenario
	Production and purchase location	Scenario
	Distance below sealed surfaces between both locations	Scenario
	Distance below greenfield between both locations	Scenario
output data	Transport method	Hydrogen utilization
	Click or tap here to enter text.	Click or tap here to enter text.
	Click or tap here to enter text.	Click or tap here to enter text.
	Click or tap here to enter text.	Click or tap here to enter text.

Decision tree – Electrolyser



Decision tree – Electrolyser



REPORTING FORM OF DECISION TREE
CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s):	Samuel Schöffer
Quality controller(s):	Fenna van de Watering

Decision tree information (short)

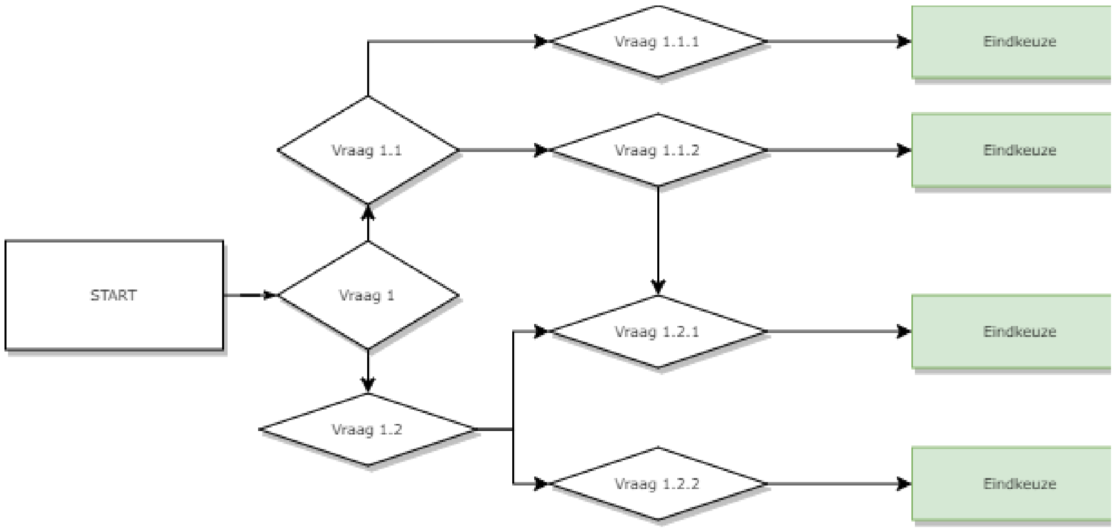
decision tree name	**Elektrolyser type and full load hours**
decision tree description (short)	**This decision tree helps deciding to select ALK or PEM and amount of hours per year**

Quality check

Subject	Check question	Conclusion
1. Title	Does the title describe the decision tree correctly?	☒ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☐ Yes It's purely a cost-based consideration.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Questions formulation	Is the question formulation clear?	☒ Yes Questions are clear.
7. Questions distinctiveness	Does the answer to the question produce a different result with different input data (perspectives and different trees)?	☐ Yes Click or tap here to enter text.
8. Order of questions	Is the order of the questions logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization questions of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: Still need to include the readiness to pay to meet extra peak demand

What are the results of the decision tree?	**Decision between Alkaline and PEM electrolysis including high, medium and low amount of full load hours.**
Which questions are asked?	1. What is the main purpose of the electrolyser?

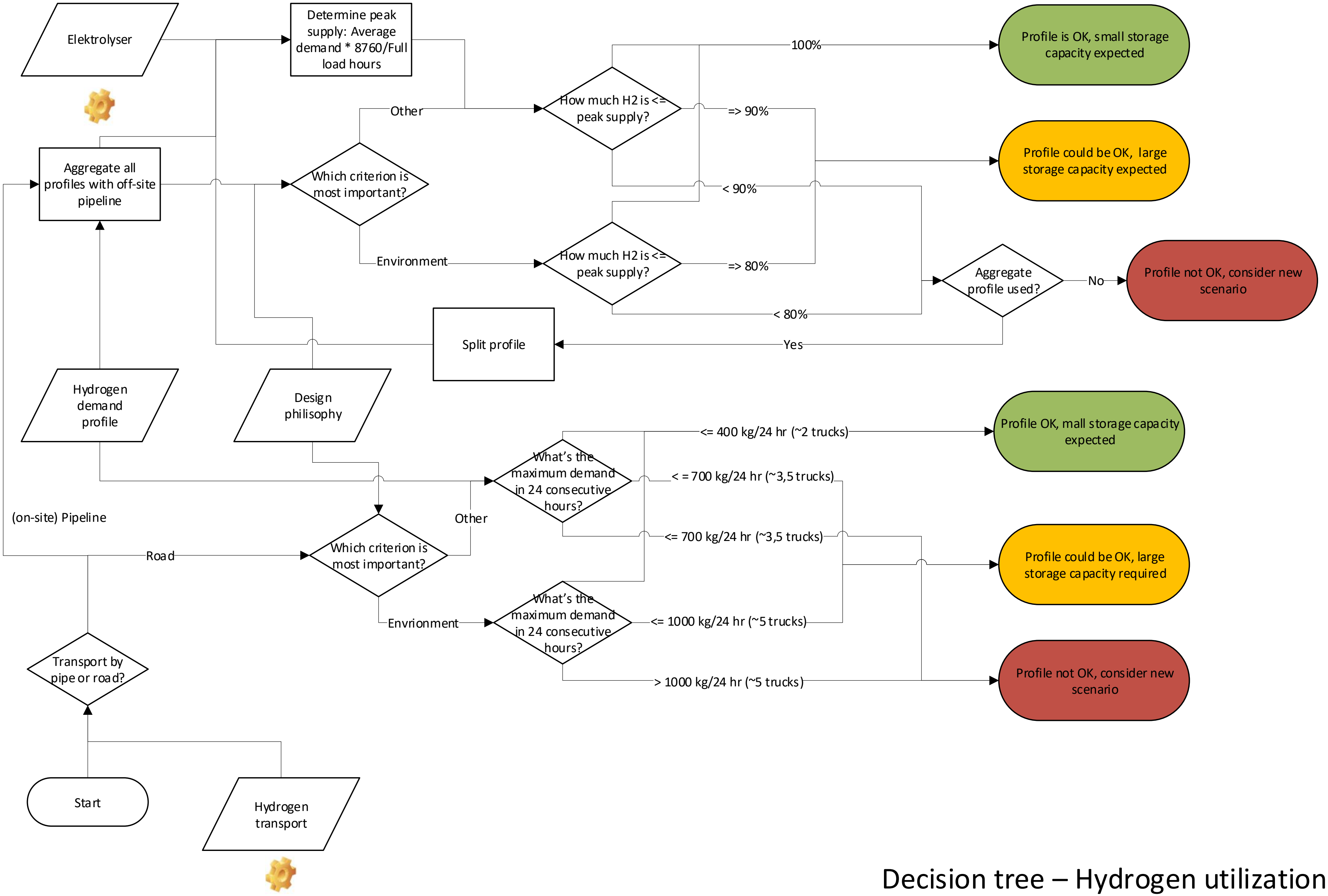


Reasoning behind the questions

Answer the following questions for each of the above (sub)questions:
- What is the number of the question, and what is the question?
- Why is this question relevant?
- Which assumptions are used for the questions and its answers?
- Is the question in the right place in the tree (order of filtering)?
- Is the question distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the questions?
- What dependencies are there, and how are the dependencies processed?

Question 1: What is the main purpose of the electrolyser?
- The question is relevant to determine the type and full load hours of electrolysers?
- The following assumptions are used:
  - The advantages of an alkaline electrolyser are that this type is cheaper and more efficient compared to a PEM electrolyser;
  - The advantage of a PEM electrolyser is that it deals much better with fluctuating load than an alkaline electrolyser
  - 8000 full load hours represents a high amount of full load hours and relatively small installed capacity;
  - 5000 full load hours represents a medium amount of full load hours and installed capacity;
  - 2000 full load hours represents a low amount of full load hours and large installed capacity;
  - Continuous hydrogen production requires a high amount of full load hours.
  - Grid stabilization and green hydrogen production require an optimum between CAPEX, full load hours and off-take of renewable energy. This is assumed to be 5000 full load hours
  - Local renewable energy is unpredictable and requires high installed capacity to cover peak power production;
- The question is in the right place;
- The question is distinctive based on the design philosophy;
- There can be many answers to this question. We have tried to capture the most important ones and link them to these indicative answers;
- There are no dependencies on other decision trees.

	which data	from/for which decision tree?
Input data	Design philosophy	n.a.
output data	Electrolyser type Amount of full load hours Click or tap here to enter text. Click or tap here to enter text.	Hydrogen utilization System integration Residual heat Click or tap here to enter text.



Decision tree – Hydrogen utilization

REPORTING FORM OF DECISION TREE

CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s)	Samuel Schöffer
Quality controller(s):	Mascha Smith

Decision tree information (short)

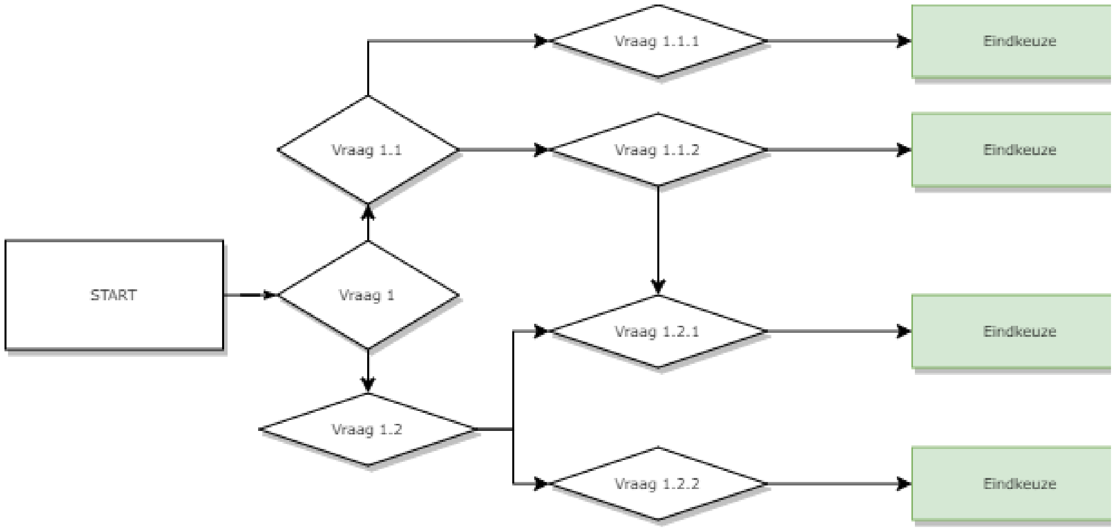
decision tree name	**Hydrogen utilization**
decision tree description (short)	**The output of this decision tree determines whether a customer's usage profile is included in the next phase.**

Quality check

Subject	Check step	Conclusion
1. Title	Does the title describe the decision tree correctly?	☐ Yes Not entirely clear
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☒ Yes Click or tap here to enter text.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Formulation	Is the step formulated clearly?	☐ Yes Steps are clear.
7. Distinctiveness	Does the step produce a different results with different input data (perspectives and different trees)?	☐ Yes No, it's purely a cost-based consideration.
8. Order of steps	Is the order of the steps logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization steps of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: Click or tap here to enter text.

What are the results of the decision tree?	**Which transport method should be chosen per customer. If the difference in cost is too small, the decision will be made at a later stage.**
Which steps are in the decision tree?	1. Transport by pipe or road? 1.1/1.2 Which criterion is most important? 1.1.1/1.1.2 How much energy is <= peak power? 1.1.1.3/1.1.2.3 Aggregate profile used? 1.2 What's the average demand? 1.2.1/1.2.2 What's the maximum demand in 24 consecutive hours?



Reasoning behind the steps

Answer the following steps for each of the above (sub)steps:
- What is the number of the step, and what is the step?
- Why is this step relevant?
- Which assumptions are used for the steps and its answers?
- Is the step in the right place in the tree (order of filtering)?
- Is the step distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the steps?
- What dependencies are there, and how are the dependencies processed?

Step 1: Transport by pipe or road?
- The step is relevant because it matters whether it can be delivered continuously (via the pipe) or in batches (by road).
- No assumptions are needed.
- It's in the right place.
- Input depends only on the transport method. This is determined in another decision tree.
- These are all possible answers to the steps. It may be that both options are still open, in which case the decision tree for both options must be completed.
- Dependency on another decision tree. This is clearly indicated.

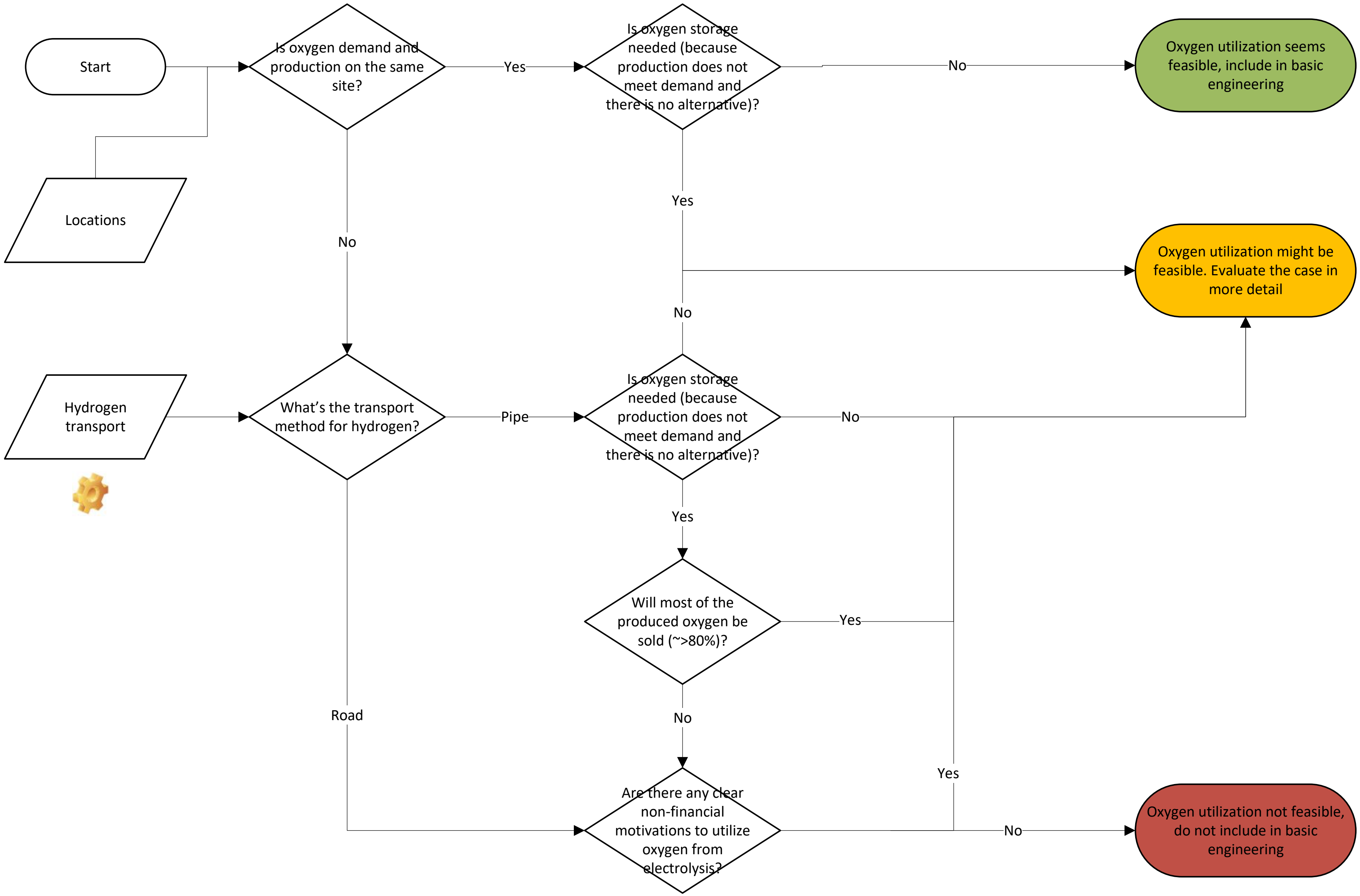
Step 1.1/1.2: What criterion is most important?
- The step is relevant because you can make other design choices if sustainability is the most important criterion.
- Assumptions:
  - From the perspectives economical, flexibility, and security of supply, there are no conflicting interests in this decision tree. These are therefore combined with the answer "other".
  - From a sustainable perspective, the criteria become less stringent in order to be able to accept more customers. The additional costs that this probably entails are accepted from this perspective.
- Step is in the right place twice
- Yes, see assumptions.
- It is based on the four above mentioned perspectives, of which only sustainable is therefore distinctive.
- Dependence on the perspective of the scenario, this is clearly indicated.

Step 1.1.1/1.1.2 How much hydrogen is <= peak supply?
- The step is relevant to estimate how well a customer can be served through a pipeline.
- Assumptions:
  - The peak supply capacity for an (aggregated) profile is determined by the average hydrogen demand and the number of full-load hours.
  - First, all customers served through a pipeline are merged. If this leads to an unfeasible profile, the profile can be viewed per customer or groups of customers.
  - The amount of hydrogen that can be delivered below the peak supply capacity is determined by not counting all hydrogen above this peak supply capacity.
  - The more hydrogen can be delivered within this peak supply capacity, the easier the customer is to operate.
  - From the sustainability perspective, a profile where:
    - 100% or more of the hydrogen demand within the capacity is feasible with small storage capacity;
    - Between 80 and 100% of the hydrogen demand within the capacity is feasible with large storage capacity;
    - Less than 80% of the capacity hydrogen demand is considered not feasible;
  - From the other perspectives, these limits are 10% higher.
- The step is in the right place.
- The step is distinctive between the perspective of "sustainability" and the other perspectives (economic, flexible, and security of supply).
- At this stage of the design process, these are all possible answers.,
- The input depends on another decision tree, the hydrogen profiles from the scenario, and the output of previous steps in this decision tree. This is clearly indicated.

Step 1.1.1.3/1.1.2.3 Aggregate profile used?
- The step is relevant if an aggregate profile is not feasible. Then it is necessary to split the profile.
- Assumptions do not apply.
- The step is in the right place.
- The step is not distinctive from different perspectives. This is not necessary either.
- The step gives all possible answers.
- The step depends on previous steps in the decision tree.

Step 1.2.1 /1.2.2 What's the maximum demand in 24 consecutive hours?
- The step is relevant to determine whether too much hydrogen demand is concentrated in a short period of time. Such a demand is difficult to deliver in batches.
- Assumptions:
  - The maximum demand in 24 consecutive hours (i.e., not necessarily from 12 AM to 12 AM) is determined for each hour by aggregating the demand of the last 24 hours.
  - From these values, the largest value is used to test whether the maximum demand in a 24-hour period is not too large.
  - From a sustainability perspective, the maximum demand is:
    - 400 kg/24 hours achievable within a normal delivery schedule;
    - 1000 kg/24 hours feasible within a normal delivery schedule with additional storage capacity with the user;
    - More than 1000 kg/24 hours not feasible.
  - From the other perspectives (economic, the security of supply, flexible/modular is a maximum demand of maximum:
    - 400 kg/24 hours achievable within a normal delivery schedule;
    - 700 kg/24 hours feasible within a normal delivery schedule with additional storage capacity with the user;
    - More than 700 kg/24 hours not feasible.
- The step is in the right place.
- The step is distinctive between the perspective of "sustainability" and the other perspectives (economic, flexible, and security of supply).
- Based on the assumptions, these are all possible answers.
- The input depends on the hydrogen profile and the perspective from the scenario. This is clearly indicated.

	which data	from/for which decision tree?
Input data	Hydrogen profile	Scenario
	Perspective	Scenario
	Transport method	Decision tree of hydrogen transport method
	Full-load hours	Decision tree of electrolyzer
output data	Feasibility hydrogen profiles	System integration and residual heat
	Click or tap here to enter text.	Click or tap here to enter text.
	Click or tap here to enter text.	Click or tap here to enter text.
	Click or tap here to enter text.	Click or tap here to enter text.



Decision tree – Oxygen

Witteveen + Bos

REPORTING FORM OF DECISION TREE

CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s):	Samuel Schöffer
Quality controller(s):	Rasyid Salam

Decision tree information (short)

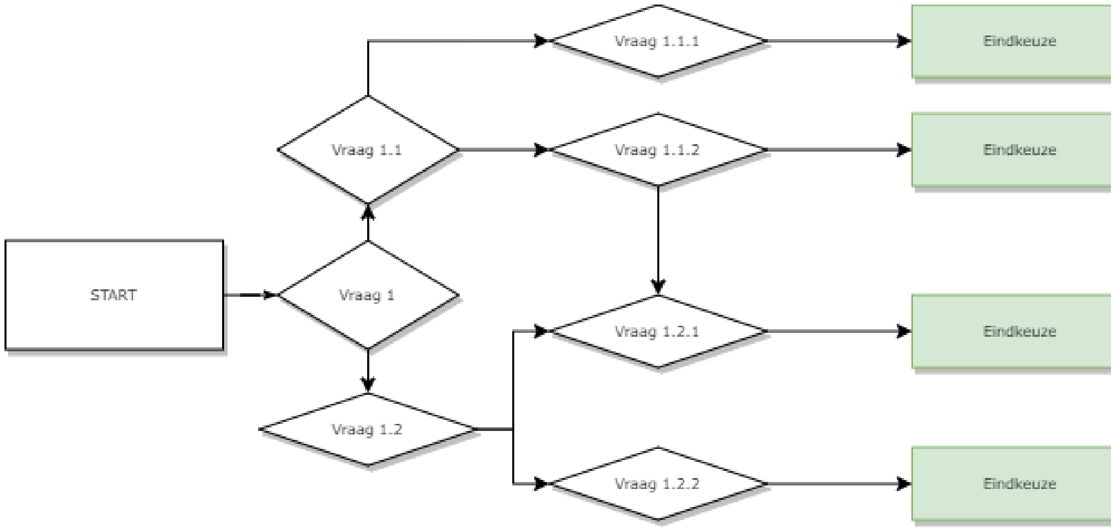
decision tree name	**Oxygen utilization and pathway**
decision tree description (short)	**This decision tree helps deciding whether or not to include oxygen utilization in the basic engineering phase**

Quality check

Subject	Check question	Conclusion
1. Title	Does the title describe the decision tree correctly?	☒ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☒ Yes Click or tap here to enter text.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Questions formulation	Is the question formulation clear?	☒ Yes Click or tap here to enter text.
7. Questions distinctiveness	Does the answer to the question produce a different result with different input data (perspectives and different trees)?	☒ Yes Click or tap here to enter text.
8. Order of questions	Is the order of the questions logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization questions of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: O2 cost reduction and options are location specific

What are the results of the decision tree?	**Whether O2 is utilized in industry (process/feedstock), medical, combustion (NOx reduction, efficiency improvement) or not at all**
Which questions are asked?	1. Is oxygen demand and production on the same site? 1.1/1.2.1 Is oxygen storage needed (because production does not meet demand and there's no alternative)? 1.2 What's the transport method for hydrogen? 1.2.2/1.2.1.1.1 Are there any clear non-financial motivations to utilize oxygen from electrolysis 1.2.1.1 Will most of the produced oxygen (~>80%) be sold?



Reasoning behind the questions

Answer the following questions for each of the above (sub)questions:
- What is the number of the question, and what is the question?
- Why is this question relevant?
- Which assumptions are used for the questions and its answers?
- Is the question in the right place in the tree (order of filtering)?
- Is the question distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all-possibleanswers to the questions?
- What dependencies are there, and how are the dependencies processed?

Question 1: Is oxygen demand and production on the same site?
- The question is relevant because on-site production and demand makes a significant different in cost;
- No assumptions;
- The question is in the right place
- The question is distinctive
- These are all the possible answers
- The answer is dependent on the location (scenario)

Question 1.1/1.2.1: Is oxygen storage needed (because production does not meet demand and there's no alternative)?
- The question is relevant because on-site production and demand makes a significant different in cost;
- Assumptions:
  - If the answer is no: only drying is needed if the user is needed and else only a pipeline. It is therefore feasible to utilize the oxygen because the additional costs are low
  - If the answer is yes: Adding storage also adds the need for compression and therefore drying as well. This makes the system significantly more expensive. In this case, there are many factors that play a role and it is therefore impossible to make a decision at this point.
- The question is in the right place
- The question is distinctive
- These are all the possible answers
- No dependencies

Question 1.2: What's the transport method for hydrogen?
- The question is relevant because transport is significantly cheaper if it can be done combined with hydrogen;
- Assumptions:
  - If the answer is pipe: In this an oxygen pipeline can be constructed together with the hydrogen pipeline reducing the transportation costs significantly
  - If the answer is road: Transport by road is expensive and it also required storage capacity and therefore also compression and drying. This increases the costs so much that is no longer financially feasible/
- The question is in the right place
- The question is distinctive
- These are all the possible answers
- Depends on the hydrogen transport method

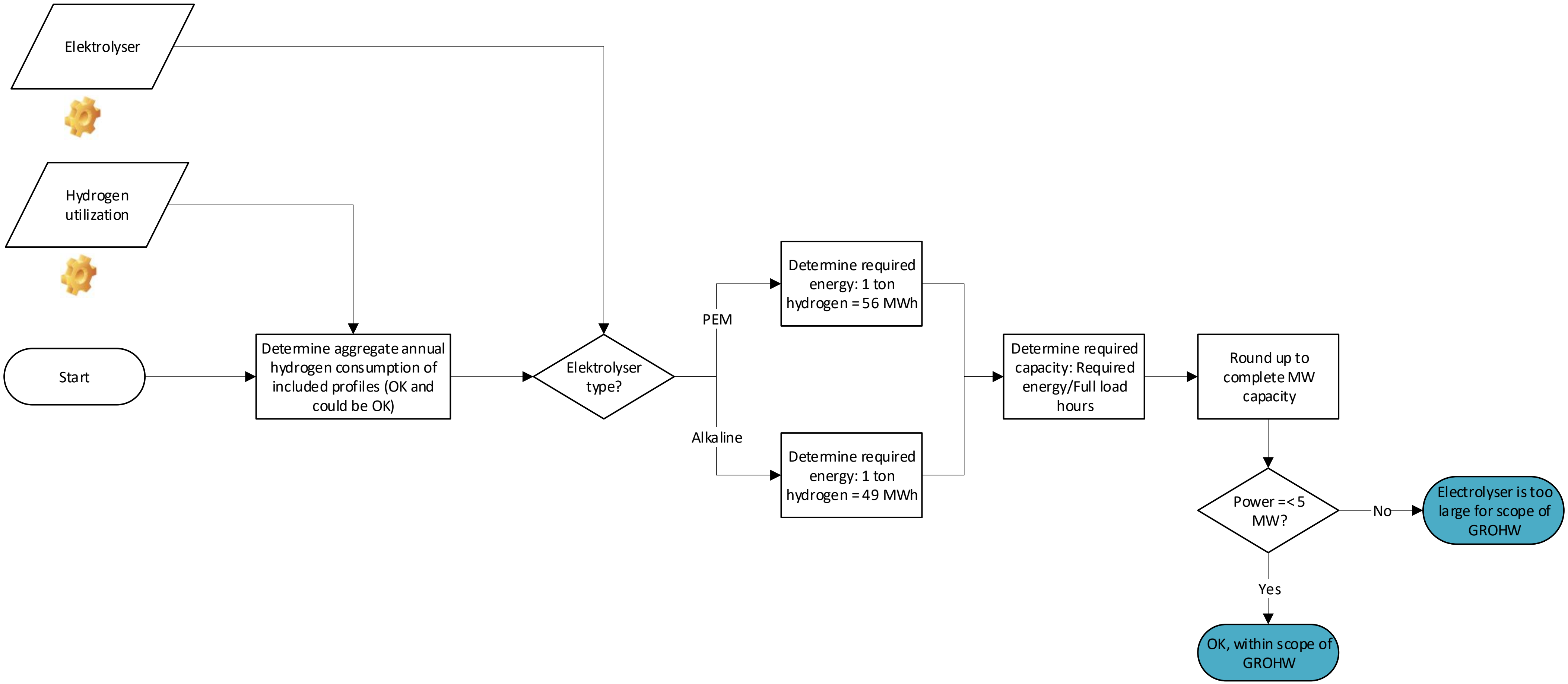
Question 1.2.2/1.2.1.1.1: Are there any clear non-financial motivations to utilize oxygen from electrolysis
- The question is relevant because not only money matters;
- It is assumed that it is worth to further evaluate if other things than money matter significantly
- The question is in the right place
- The question is distinctive
- These are all the possible answers
- No dependencies

Question 1.2.1.1: Will most of the produced oxygen (~>80%) be sold?
- The question is relevant because if there's enough economy of scale it could be feasible
- Oxygen utilization benefits from economy of scale. It depends on many factors. It is therefore advised to further evaluate a case if the oxygen demand matches the production well.
- The question is in the right place
- The question is distinctive
- These are all the possible answers

No dependencies

	which data	from/for which decision tree?
Input data	Location Hydrogen transport method Click or tap here to enter text.	Click or tap here to enter text. Hydrogen transport Click or tap here to enter text. Click or tap here to enter text.
output data	Feasibility for oxygen utilization Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.	Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.

Decision tree - Systeem Integration



REPORTING FORM OF DECISION TREE

CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s):	Samuel Schöffer
Quality controller(s):	Mascha Smith

Decision tree information (short)

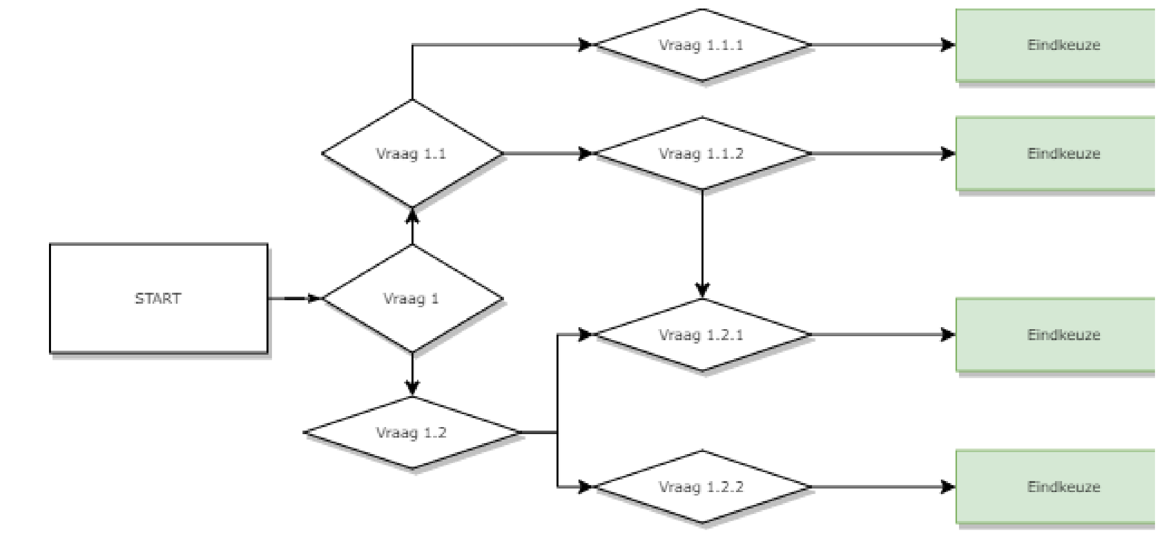
decision tree name	**Hydrogen utilization**
decision tree description (short)	**The output of this decision tree determines whether a customer's usage profile is included in the next phase.**

Quality check

Subject	Check step	Conclusion
1. Title	Does the title describe the decision tree correctly?	☐ Yes The title suggests more content than it now has
2. Scope	Do you get the right information by walking through this decision tree?	☐ Yes same as above
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☒ Yes Click or tap here to enter text.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Formulation	Is the step formulated clearly?	☐ Yes Steps are clear.
7. Distinctiveness	Does the step produce a different results with different input data (perspectives and different trees)?	☐ Yes No, it's purely a cost-based consideration.
8. Order of steps	Is the order of the steps logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization steps of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: Click or tap here to enter text.

What are the results of the decision tree?	**Which transport method should be chosen per customer. If the cost difference is too small, the decision is determined at a later stage.**
Which steps are in the decision tree?	1. Electrolysis Type? 2. Power <= 5 MW?



Reasoning behind the steps

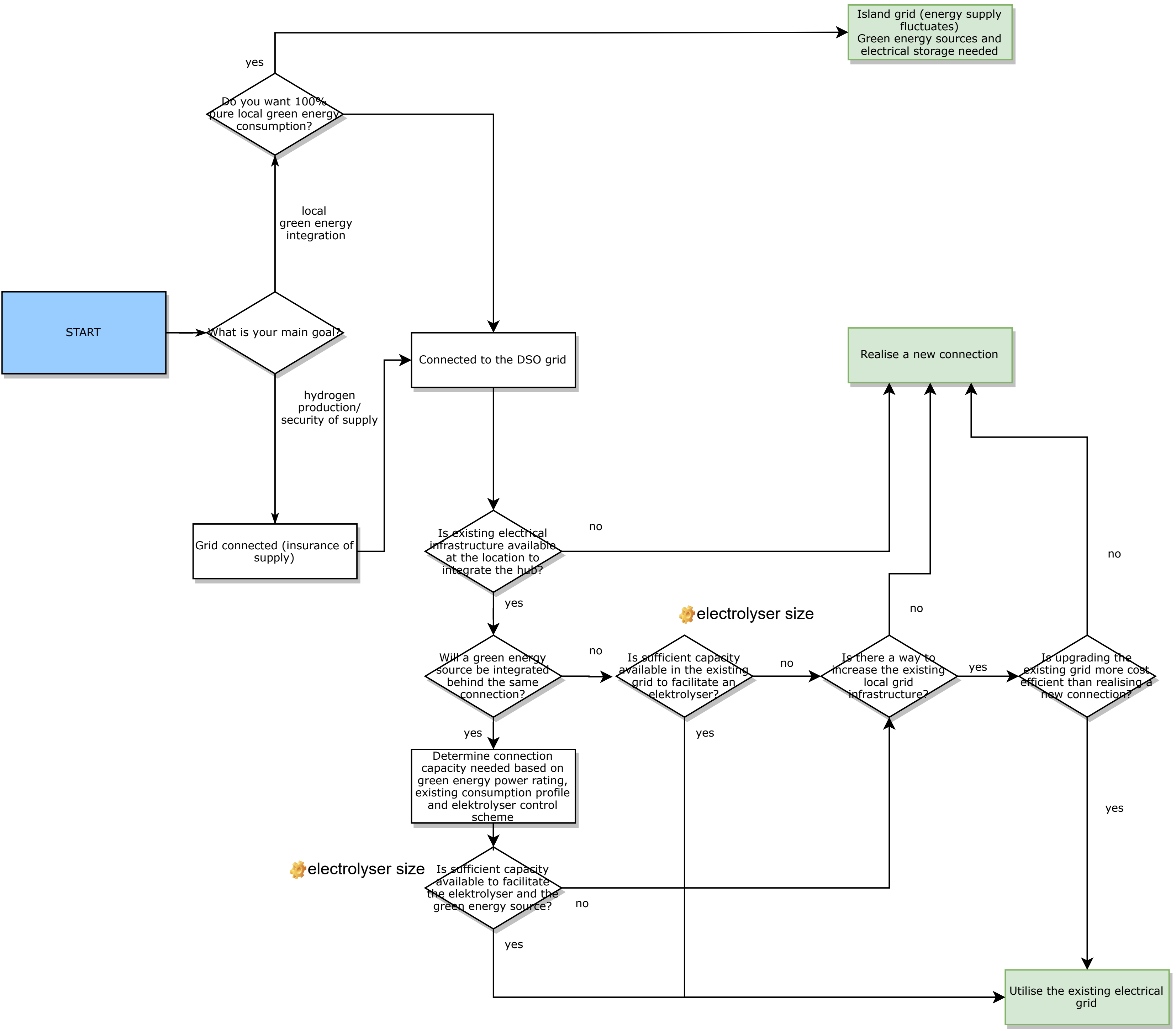
Answer the following steps for each of the above (sub)steps:
- What is the number of the step, and what is the step?
- Why is this step relevant?
- Which assumptions are used for the steps and its answers?
- Is the step in the right place in the tree (order of filtering)?
- Is the step distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the steps?
- What dependencies are there, and how are the dependencies processed?

Step 1: Electrolyser type?
- This step is relevant because the efficiency depends on the type of electrolyser;
- Assumptions:
  - The higher heating value of hydrogen is 142 MJ/kg;
  - A PEM electrolyzer has an efficiency of 70% (HHV). One ton of hydrogen, therefore, requires 56 MWh of energy.
  - An alkaline electrolyzer has an efficiency of 80% (HHV). One tonne of hydrogen, therefore, requires 49 MWh of energy.
  - The capacity of the electrolyzer is determined on the basis of the total amount of required energy and the number of full-load hours. This is rounded upwards on the whole MW.
- The step is in the right place.
- The step is distinguished by the input data as it should be.
- It's all possible answers.
- The input depends on the hydrogen demand, the type of electrolyzer, and the number of full-load hours. This is all clearly stated.

Step 2: Power <= 5 MW?
- The step is relevant to see if the project falls within the scope of GROHW.
- We assume that the maximum size of an electrolyzer within the scope of GROHW is 5 MW.
- The step is in the right place.
- The step is sufficiently distinctive.
- These are all possible answers. We assume there’s no grey area.
- The demand depends on data earlier in the decision tree. This is clearly indicated.

	which data	from/for which decision tree?
Input data	Total hydrogen demand Electrolysis type Full-load hours	Decision tree hydrogen utilization Decision tree electrolyzer Decision tree electroyser
output data	Electrolyser power Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.	Residual heat Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.

Electrical distribution - step 1



Electrical distribution - step 2

AC/DC
HV/MV/LV

To be determined in a later phase of the project.

REPORTING FORM OF DECISION TREE ELECTRICAL DISTRIBUTION

Information on authors & quality controllers

	Name
Author(s)	Isabelle Vlasman
Quality controller(s):	Paul Bougie

Decision tree information (short)

decision tree name	**Electrical distribution**
decision tree description (short)	**Determine global electrical infrastructure design choice for the electrolysis**

Quality check

Subject	Check question	Conclusion
1. Title	Does the title describe the decision tree correctly?	☒ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☒ Yes Click or tap here to enter text.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes
6. Questions formulation	Is the question formulation clear?	☒ Yes Clear question formulation
7. Questions distinctiveness	Does the answer to the question produce a different result with different input data (perspectives and different trees)?	☒ Yes Click or tap here to enter text.
8. Order of questions	Is the order of the questions logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization questions of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

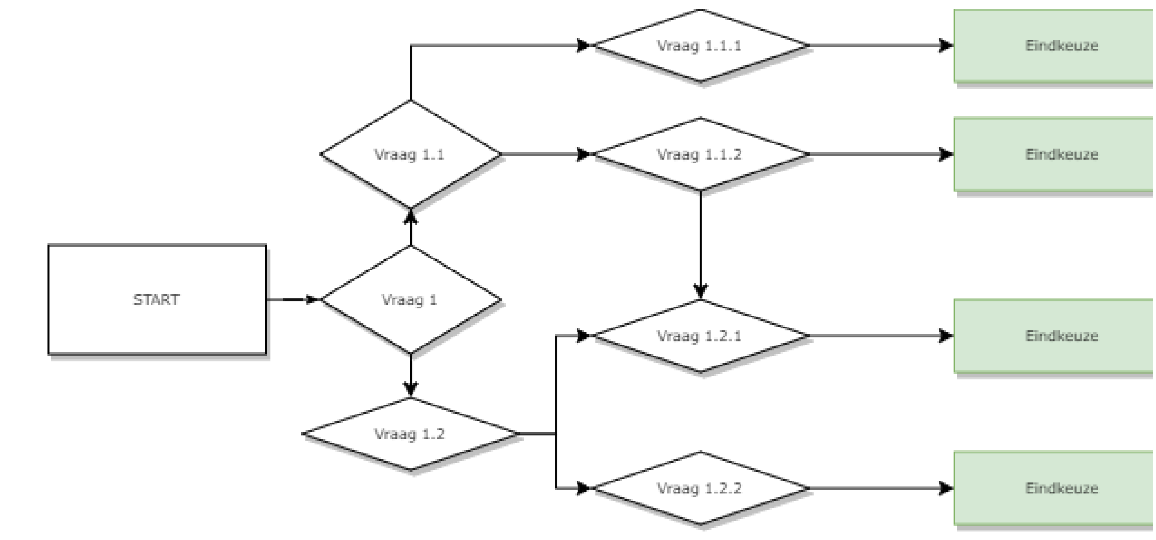
Other comments from quality controller: The only doubt I had was the 100% pure green energy. It doesn't always have to be made locally. With green certificates, it can also be done via a grid connection with 100% renewable energy, but from previous discussions with Isabelle, I understood that this scenario is not included in this case, and the focus is really on own generation.

Decision tree information (long)

What are the results of the decision tree?	**Island grid/realize new connection/use existing connection**

Which questions are asked?

1. **Question 1: What is your main goal?**
2. **Question 2: Do you want 100% pure local green energy consumption?**
3. **Question 3: Is existing electrical infrastructure available at the location to integrate the hub?**
4. **Question 4: Will a green energy source be integrated in the same connection?**
5. **Question 5: Is sufficient capacity available in the existing grid to facilitate an electrolyzer?**
6. **Question 6: Is sufficient capacity available in the existing grid to facilitate the electrolysis and the green energy source?**
7. **Question 7: Is there a way to expand the existing local grid infrastructure?**
8. **Question 8: Is upgrading the existing grid more cost-efficient than realizing a new connection?**



Reasoning behind the questions

Answer the following questions for each of the above (sub)questions:
- What is the number of the question, and what is the question?
- Why is this question relevant?
- Which assumptions are used for the questions and its answers?
- Is the question in the right place in the tree (order of filtering)?
- Is the question distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the questions?
- What dependencies are there, and how are the dependencies processed?

Question 1: What is your main goal?
This question is important because it determines whether you base your design on the demand of hydrogen and security of supply (a grid connection makes a big contribution to this) or on the integration of green energy sources and an island grid (for the latter an island grid is not ruled out directly, as for the former). So, this first question serves to investigate the possibility of designing an island grid. It is assumed here that security of supply is important when your main goal is to produce hydrogen, as described earlier. In addition, the assumption implies that if the main goal is modularity, this is related to the future scaling up of green energy sources and therefore results in creating a design involving the integration of green energy sources.

Question 2: Do you want 100% pure local green energy consumption?
By asking this question, one can ultimately determine whether or not an island grid is still an option. 100% local green energy means the electrolyzer won't get any power from the grid. Therefore, a connection to the grid is not used for supplying the electrolyzer power. This results in an island grid with no connection to the grid of the main grid.

Question 3: Is existing electrical infrastructure available at the location to integrate the hub?
If there is no existing electrical infrastructure at all, but one wants to be connected to the grid, it automatically means that a new connection has to be realized.

Question 4: Will a green energy source be integrated behind the same connection?
This is important because the electrolyzer and the green energy source work synergistically: the electrolyzer can compensate for the green energy production, provided it is properly controlled. However, both also bring their own peak power, (although in different directions).

Question 5: Is sufficient capacity available in the existing grid to facilitate electrolysis?
When there is no local green energy source, the electrolyzer will take all its power from the grid. When there is already existing electrical infrastructure, it is most profitable and sustainable to use it. However, the existing electrical infrastructure must have sufficient capacity to facilitate the power demand of the electrolyzer.

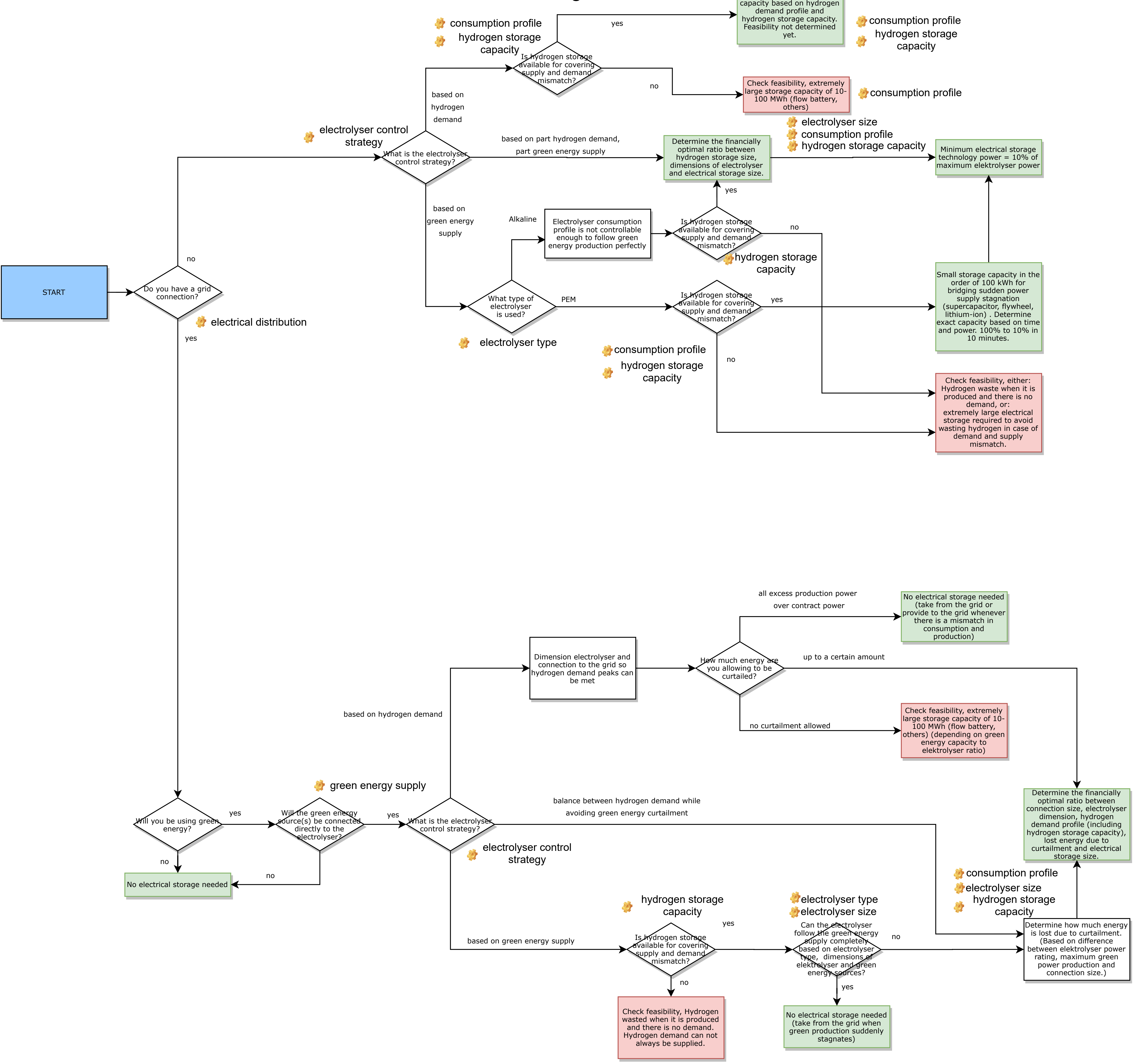
Question 6 Is sufficient capacity available in the existing grid to facilitate the electrolysis and the green energy source?
When existing electrical infrastructure is already in place, then it is the most cost-effective and sustainable to use. However, both the local green energy sources and the electrolyzer cause new power flows in this infrastructure. There must be sufficient capacity available for coping with these effects.

Question 7: Is there a way to increase the existing local grid infrastructure?
Suppose the existing grid does not have sufficient capacity for the energy systems which are needed to be integrated. In that case, it can be reinforced by, for example, replacing or adding transformers, distributors, and cables. However, the connection with the grid operator must be large enough for this, and there must be enough space for it, for example.

Question 8: Is upgrading the existing grid more cost-efficient than realizing a new connection?
It may be possible that the existing network can be extended or reinforced with a great deal of difficulty. However, sometimes it has been there for so long, and so many modifications need to be made that a new connection is a better option.

	which data	from/for which decision tree?
Input data	Main goal	Scenario
	Percentage of green hydrogen	Scenario
	Existing electrical infrastructure availability	Scenario
	Existing electrical infrastructure capacity	Scenario
	Existing infrastructure expansion possibilities	Scenario
	Local green energy sources	Scenario
	Electrolyzer power	System integration
output data	Electrical infrastructure	Electrical storage

Electrical storage



REPORTING FORM OF DECISION TREE
ELECTRICAL STORAGE

Information on authors and quality controllers

	Name
Author(s):	Isabelle Vlasman
Quality controller(s):	Click or tab after input

Decision tree information (short)

decision tree name	**Electrical storage**
decision tree description (short)	**Determine global design choice for electric energy storage**

Quality check

Subject	Key	Conclusion
1. Title	Does the title define the decision tree correctly?	☐ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☐ Yes Click or tap here to enter text.
3. Input data	Are all input data (perspectives and other trees) processed correctly?	☐ Yes Click or tap here to enter text.
4. Output data	Are all output data processed correctly?	☐ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions made correct?	☐ Yes Click or tap here to enter text.
6. Questions formulation	Is the question formulation clear or (not multi-interpretable)?	☐ Yes Click or tap here to enter text.
7. Questions distinctiveness	Does the answer to the question produce a different result with different input data (perspectives and different trees)?	☐ Yes Click or tap here to enter text.
8. Order of questions	Is the order of the questions logical and correct?	☐ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization questions of the decision tree been adequately answered?	☐ Yes Click or tap here to enter text.

Other comments from quality controller: Click or tap here to enter text.

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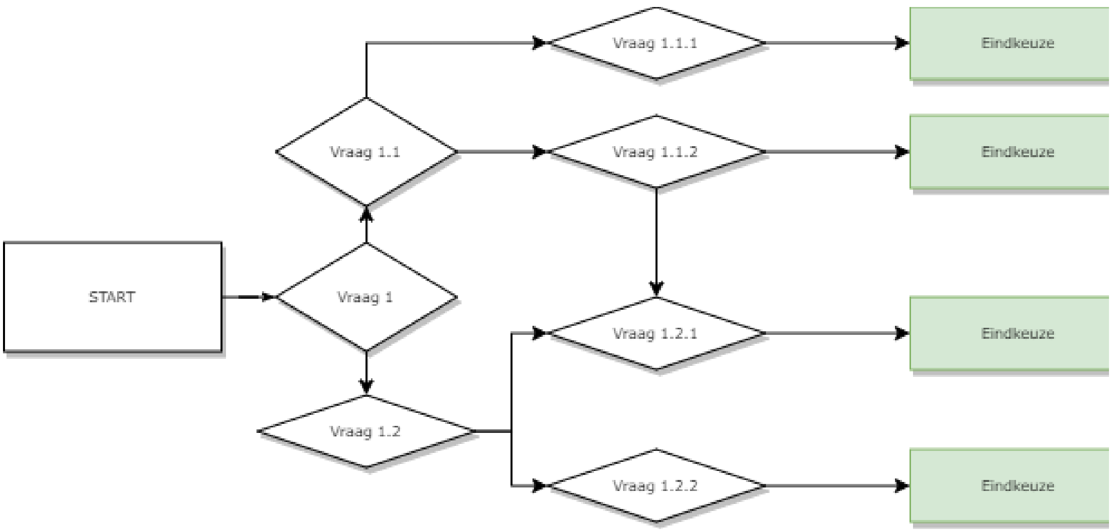
Decision tree information (long)

What are the results of the decision tree?	**No additional electrical storage needed/check the feasibility of previous design choices because additionally needed electrical storage is too large, or hydrogen production is wasted/determine electrical storage capacity based on simulations considering among others: electrolyzer power, electrical connection capacity, price of electrical storage, local green energy production, electrolyzer control strategy, hydrogen consumption profile, hydrogen storage capacity, etc.**
Which questions are asked?	**1. Do you have a grid connection?** **2. What is the electrolyzer control strategy?** **3. What type of electrolyzer is used?** **4. Will you be using green energy?** **5. Will the green energy source(s) be connected directly to the electrolysis?** **6. What is the electrolyzer control strategy?** **7. How much energy are you allowing to be curtailed?** **8. Can the electrolyser follow the green energy supply completely based on dimensions of electrolyzer and green energy sources?**



Reasoning behind the questions

Answer the following questions for each of the above (sub)questions:
- What is the number of the question, and what is the question?
- Why is this question relevant?
- Which assumptions are used for the questions and its answers?
- Is the question in the right place in the tree (order of filtering)?
- Is the question distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the questions?
- What dependencies are there, and how are the dependencies processed?

Question 1: Do you have a grid connection?
Before determining the extent to which electrical energy storage will apply, it is important to determine whether the electrolysis is connected to the grid operator's network. A connection ensures that the electrolysis can always be supplied power when it demands it and does not make the energy supply dependent on local green energy production, which, as is generally known, can be rather erratic.

Question 2: What is the electrolyzer control strategy?
The electrolyzer can compensate green energy production very well, as it can consume sustainably generated energy on demand. However, this must be controlled, especially in an island grid. Three different degrees have been adopted: 1. Full control based on green energy (which will be the best synergy between green energy source and electrolyzer). 2. Hydrogen-based control or constantly in operation (chance of a major mismatch between generation and consumption) and something in between (slight mismatch between power generation and consumption).

Question 3: What type of electrolyzer is used?
When the electrolyzer consumption profile is based on the green energy supply, this provides a good match between generation and consumption and thus no remaining green energy needs to be curtailed. However, certain types of electrolyzers can react faster than others. The most commonly used technology, alkaline, has a long response time. The rapidly fluctuating power characteristics of green energy sources cannot be captured by an alkaline electrolyzer. An additional energy storage medium could be of service to absorb these fast fluctuations and continue to feed the slow alkaline electrolyser more gradually. A PEM electrolyzer can respond more quickly and is able to follow the fluctuating power profiles of green energy sources, provided that it has been warmed up and runs at at least 10% of its maximum power.

Question 4: Will you be using green energy?
This question is asked when there is a connection with the grid. The assumption is that green energy is certainly used in case of an island grid. Otherwise, there is no energy supply. However, when there is a connection to the grid, the electrolyzer can simply run on grey energy, which can always be supplied to match demand. Additional electrical energy storage has no added value.

Question 5: Will the green energy source(s) be connected directly to the electrolyzer?
In case the electrolyzer is using green energy, this might be provided through the grid when it is purchased by means of certificates. Technically, however, this makes no difference for the configuration of the system in comparison with an electrolyser running on grey energy. The electrolyzer consumes energy that the grid supplies on demand. Electrical energy storage is of no use in that situation. However, when local green energy sources are integrated into the same local network, energy storage can become valuable to solve the mismatch between local generation and consumption in the local distribution network.

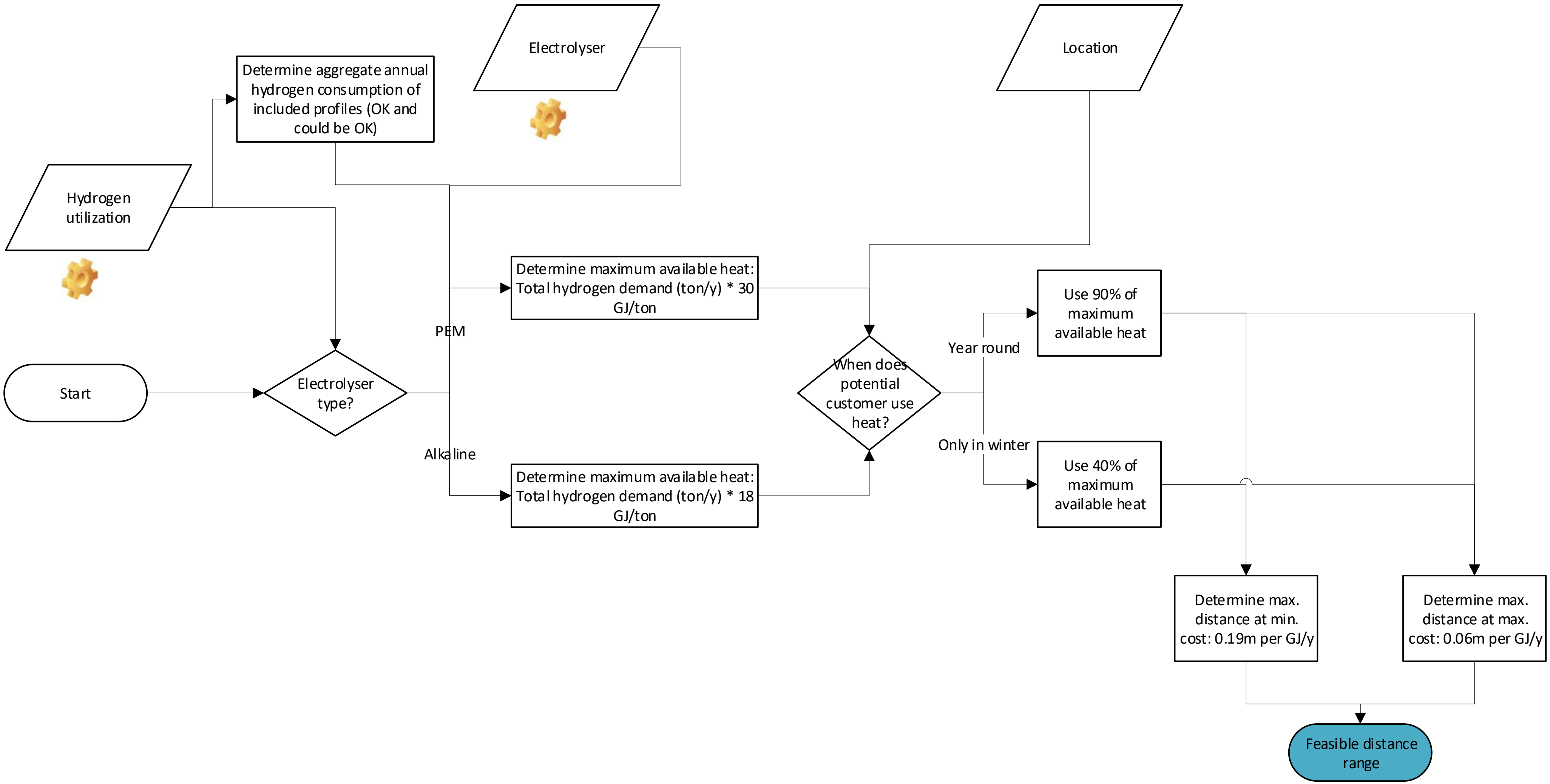
Question 6: What is the electrolyzer control strategy?
Again, three different answers to this question have been presented in this decision tree, similarly to question 2. A control strategy based on hydrogen or constant operation does nothing to improve the synergy between green energy production and electrolyzer. The connection to the grid forms a buffer to solve this problem, but it also has its limitations and boundary conditions. The connection to the grid, the green energy source, the electrolyser and the hydrogen consumption profile must be well adapted to each other for a good design. A control strategy based on green energy production stimulates synergy all the better. Of course, there is still a whole spectrum of control options between these two extremes, but this cannot be summed up in a simple decision tree. That's why the 'balance between hydrogen demand while avoiding green energy curtailment' has been chosen as an intermediate form. When the electrolyser is controlled in this way, the energy storage can only be determined on the basis of simulations and calculations with the properties of the connection, the electrolyser, the hydrogen consumption profile, and the green energy sources.

Question 7: How much energy are you allowing to be curtailed?
When the electrolyzer is controlled on the basis of hydrogen demand, is connected to the grid and green energy sources are present in the local grid, there is often a mismatch between electrical energy demand and supply. The starting point is that the connection is not dimensioned to the most extreme power peaks of green energy production, because this is extremely cost-inefficient. It will, therefore, prevent more green energy from being produced than can be lost. This can be wasted by means of curtailment. However, the question is how much one allows to be curtailed. When all excess energy generated can be curtailed, additional electrical energy storage is not necessary. When no green energy can be thrown away, all excess energy must be stored in electrical energy storage, because the electrolyzer is controlled on the basis of the hydrogen demand. The energy contained in these infrequent power production peaks can result in large values. It is unrealistic to design a battery based on this, because the costs will be many times higher than the benefits. However, there is also a middle way possible: adding a battery that absorbs part of the production peaks to a certain extent. However, the properties of this can only be determined on the basis of extensive consideration based on calculations and simulations.

Question 8: Can the electrolyzer follow the green energy supply completely based on electrolyzer type, dimensions of electrolyser and green energy sources?
When the electrolysis is based on green energy production, there will be an optimal synergy between green energy source and electrolyzer, provided that the electrolyzer is dimensioned sufficiently large and can respond sufficiently quick (alkaline performs worse PEM when it comes to response times). There is a considerable chance that the ability of the electrolysis is not as large as the maximum peak power of the green energy sources because the profiles of the latter can be much more fluctuating. Also, the connection is not normally dimensioned to these large peaks from the point of view of cost-efficiency. The addition of a small battery to capture these peaks is usually a more cost-effective choice than scaling up the connection of the electrolysis.

	which data	from/for which decision tree?
Input data	Local green energy sources	Scenario
	Hydrogen storage capacity	Scenario
	Electrolyzer control strategy	Scenario
	Electrical infrastructure	Scenario
	Electrolyzer type	Electrolyser
	Electrolyzer power	System integration
	Hydrogen consumption profiles within the scope	Hydrogen utilization
output data	Electrical storage capacity	-
	Electrical storage power	-

Decision tree – Residual heat



REPORTING FORM OF DECISION TREE
CLICK OR TAP HERE TO ENTER TEXT.

Information on authors and quality controllers

	Name
Author(s):	Samuel Schöffer
Quality controller(s):	Wim Beltman, Richard van Leeuwen

Decision tree information (short)

decision tree name	**Residual heat**
decision tree description (short)	**This decision tree gives a distance from the electrolyzer potential residual heat users, within which would it be interesting to take into account in the future**

Quality check

Subject	Check step	Conclusion
1. Title	Does the title describe the decision tree correctly?	☒ Yes Click or tap here to enter text.
2. Scope	Do you get the right information by walking through this decision tree?	☒ Yes Click or tap here to enter text.
3. Input data	Is all input data (perspectives and other trees) processed correctly?	☒ Yes It's purely a cost-based consideration.
4. Output data	Is all output data processed correctly?	☒ Yes Click or tap here to enter text.
5. Assumptions	Are the assumptions correct?	☒ Yes Click or tap here to enter text.
6. Formulation	Is the step formulated clearly?	☐ Yes Steps are clear.
7. Distinctiveness	Does the step produce a different results with different input data (perspectives and different trees)?	☐ Yes No, it's purely a cost-based consideration.
8. Order of steps	Is the order of the steps logical and correct?	☒ Yes Click or tap here to enter text.
9. Decision tree rationalization	Have all the rationalization steps of the decision tree been adequately answered?	☒ Yes Click or tap here to enter text.

Other comments from quality controller: Click or tap here to enter text.

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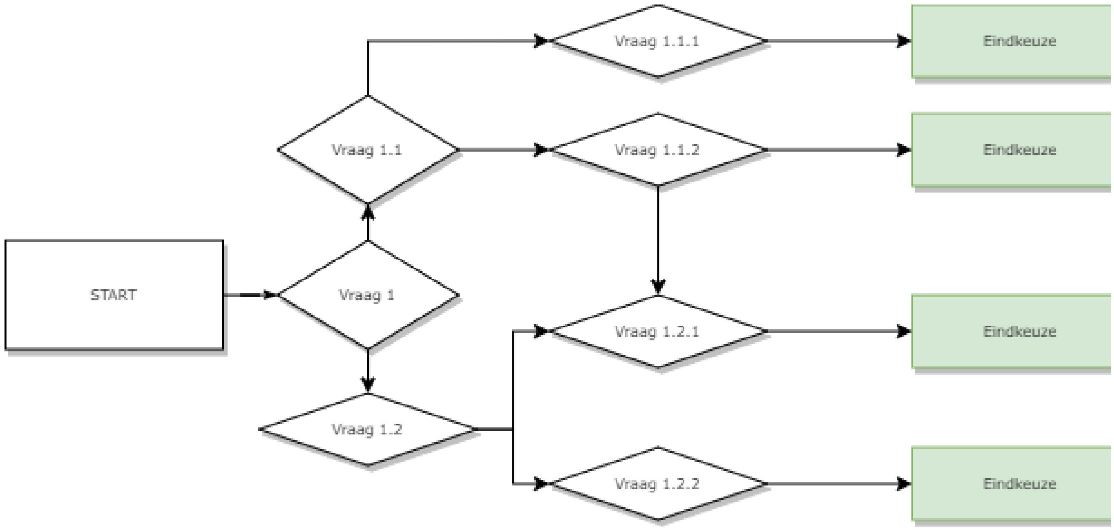
What are the results of the decision tree?	**Which transport method should be chosen per customer. If the difference in costs is too small, the decision will be made at a later stage.**
Which steps are in the decision tree	1. Electrolyser type? 2. Determine the maximum available heat 3. When does the potential customer use heat? 4. Determine the distance



Reasoning behind the steps

Answer the following questions for each of the above (sub)steps:
- What is the number of the step, and what is the step?
- Why is this step relevant?
- Which assumptions are used for the steps and its answers?
- Is the step in the right place in the tree (order of filtering)?
- Is the step distinctive within the possible input data? (input is scenario + input from other decision trees)
- Why are these all possible answers to the steps?
- What dependencies are there, and how are the dependencies processed?

Step 1: Electrolysis Type?
- This step is relevant because the amount of residual heat depends on the type of electrolyser
- Assumptions are not applicable.
- The step is in the right place.
- The step is distinguished by the input data as it should be.
- It's all possible answers.
- The input depends on the type of electrolysis

Step 2: Determine maximum available heat
- This step is relevant to determine the maximum amount of heat
- Assumptions:
  - The higher heating value of hydrogen is 142 MJ/kg;
  - 50% of the energy that is not converted into hydrogen can be used as residual heat
  - A PEM electrolyzer has an efficiency of 70% (HHV). For one ton of hydrogen, 30 GJ residual heat is produced;
  - An alkaline electrolyzer has an efficiency of 80% (HHV). For one ton of hydrogen, 18 GJ residual heat is produced;
- The step is in the right place.
- The step is distinguished by the input data as it should be.
- It's all possible answers.
- The input depends on the type of electrolyzer and the total hydrogen demand

Step 3: When does the potential customer use heat?

- Potential heat users are not always in demand for heat. This makes a big difference in the business case.
- Assumptions:
  - A distinction is made between two types of customers:
    - Customers who always have a heat demand. In this case, 90% of the maximum available residual heat can be utilized.
    - Customers who only have heat demand in winter. In this case, 40% of the maximum available residual heat can be utilized.
- The step is in the right place.
- The step is sufficiently distinctive.
- Of course, there are several types of customers to think of. With these two types, however, we will have covered the vast majority. This is considered sufficient for this stage
- Input depends on the scenario, what type of customers are closer to the production site.

Step 4: Determine the distance

- This provision indicates the final output of the decision tree.
- Assumptions:
  - The distance is determined by equating the expected costs with the expected revenues. Both are explained below.
  - The expected revenue is determined by assuming that:
    - The residual heat that can be utilized is sold for a period of 30 years. This is longer than the life of the electrolyzer. However, a heat line or grid has a much longer life span. Instead of counting on a residual value, the value of residual heat sales for this longer lifetime is determined;
    - The discount rate is 3%;
    - The price of heat is equivalent to a natural gas price of EUR 0,25/Nm^3. This equates to EUR 7.91/GJ.
  - For the expected costs, it is determined by assuming that:
    - The investment costs for the heat pipeline itself are by far the largest. Other costs are neglected.
    - The costs for a heat pump is out of scope.
    - The minimum cost of a heat line is EUR 800/m. The maximum distance is determined on the basis of this.
    - The maximum cost of a heat line is EUR 2768/m. The minimum distance is determined on the basis of this.
  - Because the output gives a result at a very high level of detail, the perspective is not relevant in this provision.
- The step is in the right place.
- The step is distinctive by the amount of heat.
- Within the assumptions, these are all possible answers.
- Input depends on previous output in the decision tree. This is clearly indicated.

	which data	from/for which decision tree?
Input data	Total hydrogen demand Type of electrolyser Type of heat customers near the site	Decision tree hydrogen utilization Decision tree electrolyzer Scenario
output data	The distance within which residual heat is interesting to use Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.	System choice Click or tap here to enter text. Click or tap here to enter text. Click or tap here to enter text.

V

APPENDIX: MINUTES MCDA SITE SELECTION GROHW

VERSLAG

Onderwerp	Notulen Multi Criteria Analyse Locatie keuze GROHW
Project	GROHW
Projectcode	119017
Verslagnummer	20/07
Datum overleg	8 juli 2020
Plaats	Witteveen+Bos, Leeuwenbrug 8, 7411 TJ Deventer
Referentie	VSL-07-WB-119017-2-REV-A
Auteur(s)	Tijn Nederstigt
Datum verslag	31 juli 2020
Bijlage(n)	NOT-04 Locatie keuze GROHW

Aanwezig	Raphaël van der Velde	Witteveen+Bos
	Erik Verbrugge	Witteveen+Bos
	Tijn Nederstigt	Witteveen+Bos
	Rachel Marty	Enexis
	Wim Beltman	Van Dorp
	Ron Sint-Nicolaas	Gemeente Deventer
	Menno Ten Heggeler	Stichting Deventer Economisch Perspectief
	Chris Mooiweer	S/park
	Roy van Verseveld	VOS Deventer
	Jeroen Schoenmaker	Nefit Industrial
	Ernst Demmink	ACS
Afwezig	bedrijfsnaam / company	
Kopie	Gerrit Leeftink	Auping

1 BEDRIJVENTERREIN A1

Belangrijke punten die naar boven kwamen tijdens het doornemen van het bedrijventerrein A1 voor de locatie van de elektrolyser waren als volgt:
- slechts een beperkt deel van het bedrijventerrein is beschikbaar voor de elektrolyser. Dit is het gebied rondom de truck-parking aan de zuidoostkant van het terrein. Hier is ook het waterstoftankstation van Total gepland;
- de site ligt vlak naast het spoor. Dit is een punt van aandacht met betrekking tot veiligheid en vergunbaarheid en medewerking PRO Rail bij het nader uitwerken van deze locatie;
- meerdere duurzame opwerkprojecten staan gepland om het A1-bedrijvenpark, zoals zonnepanelen op de bedrijfspanden en windturbines ten noorden van het terrein. Aandachtspunt is hier dat het terrein onder het netgebied van Alliander valt. Rachel Marty geeft aan dat het onmogelijk is om de netten van Enexis en Alliander ‘aan elkaar vast te knopen’. Opwek ten noorden van de A1 zou dus alleen stroom kunnen leveren voor de elektrolyser als deze direct op het net van Alliander, of de

aansluiting van de elektrolyser zelf wordt aangesloten. Dit heeft precedenten: een windturbine boven de A1 is aangesloten op het Alliander hoogspanningsstation in Zutphen omdat er niet genoeg restcapaciteit op Bergweide beschikbaar kon worden gemaakt.
- de nabijheid van een geplande biovergister nabij Oxe is interessant voor een eventuele gasverbinding. Op het moment is er nog geen transportleiding voor gas in nabij het bedrijventerrein;
- Aan de zuidzijde is een villawijk van Epse met bewoners die ook eerder bezwaar hebben gemaakt tegen de realisatie van het bedrijvenpark;
- overall blijft het bedrijventerrein een uitermate geschikte locatie voor de elektrolyser omdat het terrein vanaf de grond wordt ontwikkeld inclusief e-aansluiting, omdat er voldoende ruimte is voor de elektrolyser met opslag, omdat het park aan de transportroute voor gevaarlijke stoffen ligt, en omdat er logische koppelkansen zijn met het geplande waterstoftankstation;

2 S/PARK

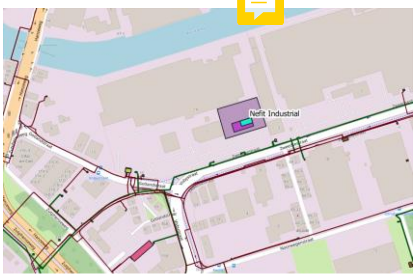
Chris Mooiweer geeft aan dat S/park geïnteresseerd is in het plaatsen van de elektrolyser op het terrein. Er is (na afloop van dit overleg geïdentificeerd door W+B team) hier bij één zoekgebieden (Noord) aan te wijzen op het terrein waar de elektrolyser inclusief opslagfaciliteit zou kunnen komen te staan. Een tweede interessante locatie bevindt zich ten zuiden van S/park. Wel wordt het belang van een business case onderstreept voordat S/park hier in mee gaat. Raphaël geeft aan dat de locatiekeuze aan de basis van de business case staat. Belangrijke voordelen van S/park als locatie zijn:
- de juiste milieucategorie (5) geschikt voor zware industrie;
- S/park beschikt over grote elektriciteitsaansluitingen waar wellicht ook de elektrolyser aan zou kunnen worden gehangen. Hier is meer onderzoek bij nodig;
- S/park ligt aan de transportroute voor gevaarlijke stoffen;
- de elektrolyser zou ook inpandig kunnen worden gebouw op het terrein van S/park;
- er is veel affiniteit met waterstof op S/park. Zo doet het bedrijventerrein mee aan een onderzoeksprogramma voor duurzame waterstof van de TU Delft, waar ook Witteveen+Bos aan deelneemt;
- er zijn potentiële afnemers van waterstof op het terrein. Dit vermindert transportlijnen.
- voor de locatie aan de Noordkant van S/park zou moeten worden onderzocht hoeveel restcapaciteit er over is op de klantaansluiting van S/park. Deze bevindt zich tegen de Zutphenseweg ten zuidoosten van het zoekgebied. Het gasafleverstation van S/park bevindt zich aan de zuidkant van het terrein. Onderzocht moet worden of dit station bi-directioneel kan worden gemaakt. Een andere optie zou intakken op het 4 bar net aan de Zutphenseweg kunnen zijn. Er is ook een intern gasnetwerk op het terrein aanwezig.
- bij de locatie ten zuiden van S/park is een elektriciteitsaansluiting en een gasafleverstation vanuit het 4 bar net aanwezig. Onderzocht moet worden of de elektrolyser op de aansluiting kan worden gezet.

S/park blijft een zeer interessante optie voor de elektrolyser maar heeft behoefte aan een business case om hier ook bestuurlijke commitment achter te krijgen.

3 ACS

ACS geeft aan kortgeleden een stuk grond ten zuiden van de asfaltcentrale te hebben aangeschaft. Hierdoor is er meer ruimte op het terrein beschikbaar dan voorheen gedacht. ACS is geïnteresseerd in dit project en heeft als company policy om op den duur op meerdere aan een elektrolyser te koppelen. Dit omdat asfaltproductie geen continu proces is maar wel een zeer grote elektriciteitsaansluiting vereist. ACS geeft dan ook aan de schaalgrootte van de beoogde elektrolyser graag groter te zien. ACS blijft een interessant zoekgebied omdat:
- de elektrolyser vrijwel zeker op de bestaande e-aansluiting kan worden aangesloten;
- er door de aanschaf van extra grond voldoende ruimte beschikbaar is voor de elektrolyser;
- ondanks dat de transportroute gevaarlijke stoffen niet langs ACS loopt zijn er mogelijkheden om de waterstof over water te vervoeren;
- het terrein heeft in ieder geval de juiste milieucategorie voor de elektrolyserp;
- ACS heeft twee elektriciteitsaansluitingen aan de noordkant en het midden van het terrein. Onderzocht moet worden op welke van deze twee de meeste restcapaciteit is. Intakken op het gasnet zou moeten worden onderzocht via het afleverstation op het midden van het terrein.

4 NEFIT INDUSTRIAL



Nefit geeft aan dat de kadastergrens van het bedrijf anders loopt dan op de kaartprojectie. Dit houdt in dat er een kleiner zoekgebied overblijft voor de elektrolyser. Het kantoor van Bosch staat vlak voor de fabriek van Nefit, en deze zorgt voor veiligheidscontouren waar ook rekening mee moet worden gehouden. Belangrijke randvoorwaarden zijn bij Nefit:
- de elektrolyser moet aan de voorzijde van de fabriek komen te staan;
- de elektrolyser moet buiten de veiligheidscontouren van Bosch staan;
- er is waarschijnlijk geen ruimte voor de elektrolyser en de opslag;
- daarnaast moet onderzocht worden of de bestaande elektriciteitsaansluiting voldoende is;
- Nefit grenst aan de transportroute voor gevaarlijke stoffen en heeft de juiste milieucategorie;
- er is voldoende fysieke ruimte en bestuurlijk draagvlak voor de elektrolyser.
- er liggen drie kleine afleverstations vlak voor Nefit Industrial waar zou kunnen worden ingetakt op het middendruknet. Stroom zou kunnen worden geleverd vanuit de klantaansluiting die zich ten westen van het zoekgebied bevindt.

5 RWZI

Ron Sint-Nicolaas geeft aan dat het daadwerkelijke terrein van de rwzi veel groter is dan op de kaart aangegeven, het strekt tot aan de uiterwaarden. Door de hoeveelheid ruimte op het terrein van de rwzi blijft het een interessante locatie om te onderzoeken. Daarnaast:
- ligt de rwzi naast het hoogspanningsstation Deventer Platvoet, waar nog ruim voldoende restcapaciteit is. Het zal dus relatief gezien een lagere investering zijn om een aansluiting aan te leggen;
- is de wijk rondom de rwzi geschikt bevonden voor Lage Temperatuur verwarming wat inhoud dat de warmte die vrijkomt bij de elektrolyse direct zou kunnen worden ingezet;

- moet wel worden erkend dat er geen geschikte milieuzonering is voor zware industrie op het terrein, en er langs het gebied geen transportroute voor gevaarlijke stoffen ligt;
- de elektriciteitsaansluiting van de rwzi bevindt zich in het midden van het terrein. Er is geen gasaansluiting, en het middendruknet bevindt zich op enige afstand ten oosten van de rwzi aan de Zwolseweg.

6 VOS DEVENTER

VOS geeft aan dat de interesse voor waterstof bij het bedrijf zeer groot is. Zeker voor long haul transport is waterstof een geschikte optie, en op meer locaties van VOS worden waterstoftankstations overwogen. Echter is er op het terrein van VOS zelf in Deventer niet voldoende ruimte om de elektrolyser (inclusief veiligheidscontour) te housen. Daarom valt VOS als locatie voor de productie af, maar zal VOS wel een belangrijke rol als afnemer kunnen spelen in de business case.

7 ROYAL AUPING

Royal Auping heeft op het terrein onvoldoende beschikbare ruimte voor de elektrolyser en valt dus af in de shortlist.

8 GASFABRIEK

De Gasfabriek heeft een terrein met een dependance van een Hogeschool en een aantal onderzoeksgebouwen en is dus als kennispartner zeer geschikt. Echter is er onvoldoende ruimte voor de elektrolyser en is er ook geen grote elektriciteitsaansluiting waardoor het terrein als locatie zou kunnen worden overwogen. S/park is hier de geschiktere kandidaat. Gasfabriek valt dus af als locatie.

9 NEXT STEPS

Tijdens deze sessie hebben we de zoeklocatie van 8 naar 5 teruggebracht. Daarnaast hebben we meer informatie kunnen verzamelen over de locatie specifieke eigenschappen. In de volgende fase gaan we met de locatie-eigenaren individueel in gesprek om zo samen tot de beste business case te komen.
We gaan dus voor alle 5 locaties een systeemverkenning uitvoeren. Daarbij heeft Ron Sint Nicolaas aangegeven dat voor de gemeente het interessanter is als er meerdere locaties gaan komen dan één locatie. Bij meerdere locaties wordt het echt een systeemonderdeel en niet een one time only project.

Vragen aan Enexis

Om de haalbaarheid van de verschillende locaties verder te zoeken zouden wij graag van Enexis horen:

- hoeveel kg H2 er op de gasstations bij de verschillende locaties zou kunnen worden ingevoerd;
- wat de kosten zijn van een nieuwe aansluiting op het 4 bar gasnet als leverancier;
- welke technische en veiligheidseisen er gelden bij de aanleg van een dergelijke aansluiting en gedurende de inbedrijfstelling;
- hoeveel restcapaciteit er is op de elektriciteitsaansluitingen die in deze notitie worden voorgesteld per locatie;

- wat de kosten zijn van een nieuwe aansluiting op het middenspanningsnet;
- welke technische en veiligheidseisen er gelden bij de aanleg van een dergelijke aansluiting en gedurende de inbedrijfstelling.

BIJLAGE: NOT-04 LOCATIE KEUZE GROHW

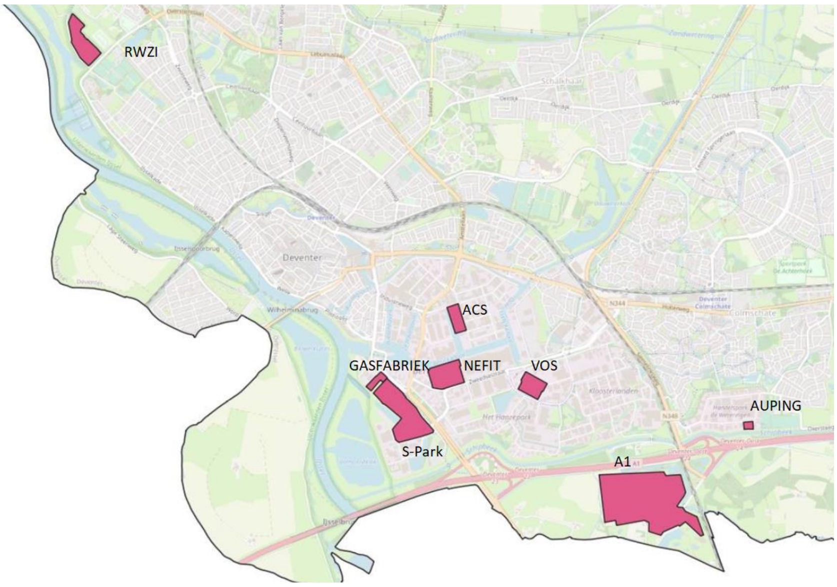
Witteveen + Bos

NOTITIE

Onderwerp	Locatie keuze GROHW
Project	GROHW
Opdrachtgever	GROHW consortium
Projectcode	119017
Status	Definitief
Datum	3 juli 2020
Referentie	NOT-04-WB-119017-2-REV-A
Auteur(s)	Erik Verbrugge
Gecontroleerd door	Raphaël van der Velde
Goedgekeurd door	Raphaël van der Velde
Paraaf	
Aan	Deelnemers MCA locatie
Kopie	Partner GROHW

Voor het GROHW project zijn we tot de conclusie gekomen dat locatie keuze voor het plaatsen van een electrolyzer voor groene waterstofproductie cruciaal is voor het vervolg van de studie. In onderstaande afbeelding zijn de beoogde locaties weergegeven.

Afbeelding 1 Beoogde locaties electrolyzer



Om volgende fases succesvol en efficiënter uit te werken zullen we ons hierom dan nu ook focussen op het kiezen van de locatie. Echter, bij de locatie keuze is input van de partners en locatie eigenaren nodig. Om deze reden nodigen we u uit op een MCDA (Multi Criteria Decision Analysis) sessie waarin we de voor-/nadelen van de locaties in kaart willen brengen vanuit uw perspectief. Daarnaast willen we ook inzicht krijgen in de mogelijkheden (ruimte/regelgeving/veiligheid etc.) van de beoogde locaties. Onderwerpen en vragen waarop we ons tijdens de sessie op zullen richten hebben betrekking op enkele randvoorwaarden omtrent de specifieke locaties: kan het en willen we het?

Onderstaande onderwerpen zullen de kern van het gesprek worden:
- draagvlak eigenaar/omgeving/gemeente;
- veiligheid eisen vanuit grondeigenaren zelf;
- beschikbare ruimte[1];
- beschikbare plaats op betreffende terreinen;
- veiligheid eisen gemeente[2];
- veiligheid eisen omtrent transport van gas;
- vergunningen[3];
- vergoedingen gebruik locatie.

[1] Op basis van opslag-keuze. Risicocontour mag waterbestemming, verkeersbestemming en groenbestemming overlappen.

[2] (=milieu cat): 5 is nodig voor electrolyser en 4 voor compressor. Halfjaar procedure om categorie aan te passen: Safety model en geluid, natuurbescherming, stikstofdiscussie, IJssel is natura 2000 gebied.

[3] Deventer: één bestemmingsplan voor alle gebouwde gebieden in de stad. Bestemmingsplan heet 'Deventer stad en dorpen'.


gle Maps
en, verkeer en plaatsen in de
© 2020 Google
Nefit
Bosch Thermotechniek BV
Nefit Industrial B.V
IP Duursma Deventer
Zweedsestraat
Kaashandel R.J. Roorda
LaJessi Ro
Prome
Haverhoek Trucks B.V
Autodealer
Domicare
og Vistraiteur B.V
Viswinkel
Basal
Gotlandstraat
FNV Regionaal Vakbondshuis Deventer
Google

VI

APPENDIX: MCDA SESSION REPORT

VERSLAG

Onderwerp	Multi Criteria Analyse
Project	GROHW
Projectcode	119017
Verslagnummer	20/09
Datum overleg	25 november 2020
Plaats	Teams
Referentie	VSL-09-WB-119017-2-REV-A
Auteur(s)	Isabelle Vlasman
Datum verslag	25 november 2020
Bijlage(n)	Powerpoint MCA Analysis

Aanwezig	Witteveen+Bos	Fenna van de Watering, Hans Smit, Erik Verbrugge Samuel Schöffer, Raphaël van der Velde, Isabelle Vlasman, Jeroen Kooiman, Jordy Smits, Marieke Wingelaar
	Rabobank	Kees de Schipper, Paul Maas (gedeeltelijk)
	MTSA	Timon Kruijk, Wil Füchten
	Van Dorp	Wim Beltman
	Engie	Benjamin
	HVE	Tanju Özel
	Auping	Gerrit Leeftink
	Vos	Roy van Verseveld
	HAN	Mascha Smit
	Coinversable	Erwin Bisschop
	Nefit	Jeroen Schoemaker
	Brandeniers	Frank Rubingh
	Hanzenet	Willem Poterman
Afwezig	BAM	Ernst Demmink, Jan Dirk Sloos
	Nefit	Klaas Borst
Kopie	Aan- en afwezigen	

INTRODUCTIE

Doel: Convergeren naar een Best Value optie.
- **belangrijkste technische ontwerpkeuzes vaststellen;**
- **locatie vaststellen.**

SCENARIO PITCHES

Economical

3 MW alkaline bij ACS (8000 vollasturen)

Sustainable

3 MW PEM bij ACS (2000 vollasturen)
4 MW PEM bij Nefit (5000 vollasturen)
3 MW PEM bij A1 (2000 vollasturen)

Security of Supply

5 MW PEM bij ACS + Nefit (5000 vollasturen)
1 MW PEM bij A1 (5000 vollasturen)

Flexible

5 MW PEM bij ACS + Nefit (5000 vollasturen)
3 MW PEM bij A1 (2000 vollasturen)

Opmerking Samuel (W+B)	Zuurstof-utilisatie niet meegenomen in de CAPEX en OPEX berekeningen.
Opmerking Hans (W+B)	CAPEX is nog in een vroeg stadium vastgesteld met een onzekerheid +100 % tot -50 %. Deze dus niet als waarheid aannemen, maar wel goed bruikbaar als vergelijkingsmateriaal.
Vraag Erwin Bisschop (Coinversable)	**Welke aannames zijn er gebruikt om 10 jaar vooruit te kijken?** Antwoord: die zit met name in de OPEX .
Vraag Raphaël van der Velde (W+B)	**Hoe zit het met de trucks bij het sustainable scenario? Hebben die geen investeringskosten?** Antwoord: we nemen aan dat we die huren, dus dat zijn dan alleen operationele kosten.
Vraag Timon Kruijk (MTSA)	**Waarom draaien de PEM elektrolysers niet 8000 uren? Die kunnen toch ook op gedeeltelijke last 8000 uur maken?** Antwoord: de 8000 uur betekenen 8000 vollasturen. Dus als een elektrolyser 8000 uur op lagere vermogens draait, levert dat minder vollasturen op.
Vraag Gerrit Leeftink (Auping)	**Waarom wordt Auping alleen via trucks van waterstof voorzien?** Antwoord: De hoeveelheid waterstof die Auping nodig heeft lijkt vooralsnog te laag om een pijplijn economisch aantrekkelijk te kunnen maken. Overigens is deze keuze niet in beton gegoten, maar dit is de eerste aanname.
Vraag Raphaël van der Velde (W+B)	**Kunnen we bestaande leidingen gebruiken van Enexis?** Antwoord: Enexis heeft niet aangegeven loze leidingen te hebben die we kunnen gebruiken. **Kunnen we synergie vinden met de ontwikkeling van duurzame energiebronnen die al in de pijpleiding zit van het DEP?** Antwoord: Alles wat in de pijpleiding zit is al voorzien van aansluitingen op het net. Daar kunnen we helaas niet bij 'meeliften'.
Vraag Annelies Boerman (Saxion)	**Waarom zijn er veel verschillende locaties in het duurzame scenario?** Antwoord: makkelijker om groene energiebronnen te integreren en makkelijker om zuurstof-utilisatie en restwarmte mogelijk te maken. Daarnaast levert dit meer differentiatie tussen de voorgelegde scenario's op, wat in deze MCA interessant is om met elkaar te kunnen vergelijken en een goede afweging tussen alle mogelijkheden te maken.

Vraag Erwin Bisschop (Coinversable)	**Waarom worden OPEX subsidies wel meegenomen en niet CAPEX-subsidies?** Antwoord: SDE++ sluit subsidies uit voor materialen. Er zijn wel mogelijkheden bekend voor constructies met een losse financiering voor 'vooronderzoek'-deel en losse subsidies voor OPEX. Stapeling van subsidies is dus onder omstandigheden mogelijk, maar alleen als demonstratie, niet als structureel scenario, zegt Tanju. Het is nu op gevoel gebaseerd dat dat de beste keuze is en eenvoudiger/met meer zekerheid door te rekenen. Onduidelijk of deze keuze differentiërend kan zijn of dat dit voor alle scenario's dezelfde richting uit kan werken. Onderzoek naar Europese subsidies loopt nog. Maar waarschijnlijk is de schaal van ons project niet groot genoeg om daar kans op te maken. Vraag is wat incentives kunnen zijn in die subsidies wanneer op kleine schaal wordt gewerkt, zoals bij ons project het geval is. Zuurstof uitkoppelen kan mogelijk rendabeler worden gemaakt door potentiële subsidie in de CAPEX. Conclusie: in de volgende fase zal beter onderzoek nodig zijn om te kijken of subsidie op CAPEX niet interessanter kan zijn dan op OPEX. Vooralsnog gaan we in deze MCA verder met de aanname dat subsidies op de OPEX meegenomen worden en niet op de CAPEX.
Vraag Tanju Özel (HVE)	**Is er rekening mee gehouden dat het aantal vollasturen impact heeft op de levensduur?** Antwoord: Aanname is dat de levensduur 10 jaar is en dat de elektrolyser in alle scenario's dat kunnen behalen. Dit moet echter wel in de restwaarde mee worden genomen, want die is hoger bij een scenario met minder vollasturen. Dat is nu niet meegenomen, maar wordt door Hans wel gevraagd aan de deelnemers om in hun achterhoofd te houden bij hun keuzes.
Opmerking Tanju Özel (HVE)	Suggestie om diensten voor de TSO en DSO kunnen ook gestapeld worden als het aantal vollasturen minder is en dat kan een positieve impact op de business case hebben. Tanju kan daar wel input over leveren. Dit wordt bij de daadwerkelijke keuzes van deze MCA later meegenomen.
Vraag Kees Schippers (Rabobank)	**Staat de waarde van 150 euro per vermeden ton CO2 vast? Is het mogelijk dat deze waarde hoger is het sustainable scenario dan in het economische scenario door andere duurzamere omstandigheden?** Antwoord: De subsidiewaarde is puur gebaseerd op de hoeveelheid vermeden CO2 en aantal vollast uren. Opmerking Benjamin Bolman van Engie: Het maximaal aantal uren dat vergoed wordt door de SDE++ is rond de 2000 uur per jaar. Meer krijg je niet. Dat heeft met de totale energiemix te maken. SDE++ groene stroom moet uit een lokale, direct geschakelde additionele groene bron komen om de waterstof groen te maken in de toekomst. Hier moet bij de volgende fase goed naar worden gekeken.

Vraag Benjamin Bolman (Engie)	**De brandstofprijs van 27 euro per MWh is wel erg rooskleurig, je kan er 50 % bij optellen. Dit heeft grote impact op de business case.** Antwoord: dit is inderdaad de huidige prijs en we weten dat die op kan gaan lopen. Groene energie moet je de Endex en niet de EPEX prijzen werken. Spotprijzen niet mee werken, want daar heb je geen zekerheid mee en daarmee kan je een project niet financieren. Conclusie: 40 tot 45 euro per MWh is gebruikelijker. Deze aanpassing moeten we direct doorvoeren in de berekening en in onze MCA-resultaten. We gaan kijken wat voor verschil dit maakt. Tanju is het hier mee eens. Het nieuwe getal is 42 EUR/MWh. Tip van Tanju: stresstest met minimum, medium en maximum prijzen doen. Dit zullen we in een volgende fase meenemen.
Opmerking Mascha Smit (HAN)	**De levensduur van de verschillende onderdelen van het systeem verschilt. Vervanging moet wel worden meegenomen in de OPEX.** Antwoord Timon (MTSA): stackleveranciers garanderen wel een levensduur van 10 jaar. Dus vervanging binnen die 10 jaar is niet van toepassing bij onze aanname. Je watersysteem moet hierbij wel goed op orde zijn, want de kwaliteit waterinput is van grote invloed op de levensduur. Als je dat goed regelt, kan je de gewenste levensduur binnen dit project borgen. Vervangingskosten buiten het project houden is echter niet mogelijk, want de waterkwaliteit en hoe je de elektrolyser gebruikt (veel aan- en uitschakelen is slechter voor de levensduur) is de verantwoordelijkheid van de gebruiker. Opmerking Samuel: Er is een beperking van de impact omdat als je meer draaiuren hebt, dan heb je ook een lager vermogen om dezelfde energie te kunnen leveren. Dus grotere vervangingskosten, hoewel minder frequent. Dit heft elkaar in een bepaalde mate op. De vervangingskosten zijn moeilijk in te schatten, omdat de levensduur nog te onzeker is. We zullen dit echter wel nog meenemen bij de keuzes die we maken bij de MCA later.
Vraag Mascha Smit (HAN)	**Waarom is het economische scenario complex voor operability?** Antwoord: Vraag en aanbod matchen is complex, doordat de elektrolyser niet flexibel is. Met een beperkte opslagcapaciteit voor de waterstof betekent dit dat distributie moeilijk is. Je moet de distributie heel zorgvuldig plannen om vraag en aanbod te kunnen matchen.
Vraag Richard van Leeuwen (Saxion)	**Waarom is het flexibele scenario juist easily operable?** Antwoord: Het is overgedimensioneerd en heeft daardoor veel aanstuurflexibiliteit.
Vraag Fenna van de Watering (W+B)	**Hebben we genoeg waarde gegeven aan NOx-uitstoot beperking? Die komt alleen terug in de DOP-waardering. De DOP-waardering heeft een weging van 1.6.** NOx-reductie kan de kosten mogelijk ook reduceren. Dat is nu niet meegenomen. We zullen dit later in de keuzes voor de MCA nog eens overwegen.

Opmerking Annelies Boerman (Saxion)	**Het DOP-criterium is niet expliciet genoeg. Duurzaamheidsaspecten verdwijnen zo in een grote hoop. Netcongestie, NOx-reductie etc. komen niet duidelijk naar voren.** Antwoord: het is moeilijk dit nu al expliciet te maken. Hoe het nu ingestoken is geeft echter wel een weergave van de scenario's en hun voordelen/nadelen ten opzichte van elkaar op dit gebied. Dus met name in de vergelijking komt goed naar voren dat sustainable en flexible scenario zijn duurzamer en economical en security of supply minder. Het was eerder voor o.a. Annelies te onduidelijk dat al die sustainable aspecten in de DOP-criterium zaten, dus die had ze graag zwaarder willen laten wegen in haar eerdere beoordeling. Dit zullen we later in de keuzes voor de MCA meenemen.
Draaiknop bij keuze MCA: zuurstofutilisatie	**Als we de waarde van zuurstofgebruik wel meenemen. Wat voor impact heeft dat? Welk scenario komt er dan beter uit?** Sustainable wordt een stuk beter voor de OPEX, door productie op locatie. Wel meer investeringskosten. Dit betekent een negatieve impact op de CAPEX. Flexible kan beter worden wat betreft OPEX, omdat het flexibel is. Echter, in dit scenario staat er een grote elektrolyser op S/Park. Zuurstof moet een kilometer getransporteerd worden, wat de rendabiliteit mogelijk tegen zal laten vallen. De CAPEX wordt ook in dit geval verhoogd als zuurstofutilisatie toegepast zal worden. Geen invloed op security of supply of economical. Utilisatie van zuurstof is daar geen realistische optie.
Draaiknop bij keuze MCA: levensduur	**Wat voor invloed heeft een verkorte levensduur van de PEM elektrolyser op de scenario's?** Afhankelijk van de levensduur die je aanneemt. Voorbeeldaanname: 5000 vollasturen vervang je halverwege, 2000 vollasturen gaat tien jaar mee. De restwaarde is dan echter ook verschillend. Security of supply maakt de meeste uren, dus daarvoor is de grootste kans op de noodzaak van vervanging voordat 10 jaar voorbij zijn. Dat levert dus meer OPEX kosten op. Geen invloed op het economische scenario, want die gaat sowieso 10 jaar mee.
Opmerking Raphaël van der Velde (W+B)	**Er is veel differentiatie tussen de operability scores, dus die hebben veel invloed op de scores.** Echter, de ranking verander niet als je de differentiatie verkleint.
Draaiknop bij keuze MCA: zwaardere weging voor DOP	**Welke invloed heeft het als we de DOP zwaarder wegen?** Sustainable en flexible komen dan beter uit de bus. Economical en security of supply komen slechter uit de bus.
Draaiknop bij keuze MCA: energiediensten voor de TSO/DSO	**Welke invloed heeft het gebruiken van de elektrolyser voor energiediensten voor de DSO en de TSO op de OPEX?** TSO kan wel al, DSO nog niet vanuit regelgeving. Vermogens zijn groot genoeg hiervoor bevestigt Tanju. Alle scenario's waarbij je veel flexibiliteit in je elektrolyser vermogensaansturing hebt komen dan beter uit de bus. Sustainable, security of supply en flexible komen dan dus beter uit de bus. Sustainable het meest, want 10 MW (6 MW op 2000 vollasturen) opgesteld, daarna flexible want 8 MW (3 MW op 2000 vollasturen) en daarna security of supply, want 6 MW.

Algemene vraag

Wat zijn de risico's dat/als wij compleet ernaast zitten?

De risico's zitten met name in het geld. Je moet het systeem kunnen bekostigen en een goede business case kunnen bouwen, wil je het realistisch maken dat dit project ook echt van de grond komt. Een gevoeligheidsanalyse op de elektriciteitsprijs zou interessant zijn. Het flexibele scenario zou meer pijn voelen bij hogere elektriciteitsprijs.

Hoge investeringskosten, kan dat een drempel zijn? Die is bij het flexibele scenario (de ranking 1) wel erg hoog namelijk.

Benjamin Bolman (Engie): Het vastleggen van afname is een probleem en daarmee een enorm risico. De prijs per kg waterstof is van groot belang. Wat is maximale prijs per kg waterstof die men wil betalen?

Kortom: de brandstofprijs maakt of breekt eigenlijk hoe realistisch daadwerkelijke implementatie is. Kosten moeten we misschien dus eigenlijk zwaarder laten wegen.

Als de productiekosten veel zwaarder wegen (5/12^{e}, 41 %), dan scoort security of supply iets beter dan flexibele.
Flexvermogen kan echter wel helpen in de business case, en dat is beter mogelijk bij het flexibele scenario dan in het security of supply scenario.

Uiteindelijke vraag:
5 MW op S/park, 1 MW op A1 bedrijventerrein. Wil je die overdimensioneren of niet?

Suggestie Tanju: transitiemodel. Eerst grijze waterstof, dan langzaamaan steeds groener. Economisch meest haalbaar. Verwachting is dat de prijzen voor brandstof stabiel blijven. Echter, vanuit de overheid gaan de vastrechtkosten voor grijze energie verhoogd worden, resulterend in een negatieve impact op de business case voor minder sustainable scenario's.

Voorstel: een tussenscenario dat verandert over de tijd door uitbreidingen.

Start met een security of supply systeem, maar wel de infrastructuur alvast klaarzetten om over te stappen naar sustainable/flexible.

Resultaat

Uiteindelijk is besloten tot een compromis tussen verschillende scenario's:

Basis:
- 5 MW op S/Park met een pijpleiding naar Nefit Industrial en ACS (5000 vollasturen)
- 1 MW op bedrijventerrein A1 (5000 vollasturen)

Toekomstige uitbreiding:
- geen uitbreidingen op S/Park.
- uitbreiding van de 1 MW elektrolyser bij de A1 naar een 3MW elektrolyser
- onbalansmogelijkheden en zuurstof-utilisatie in de toekomst toevoegen als dat mogelijk is.

BIJLAGE: MCA ANALYSIS

MCA Analysis

- Introduction
- The options
- Results and discussion

Goal of today

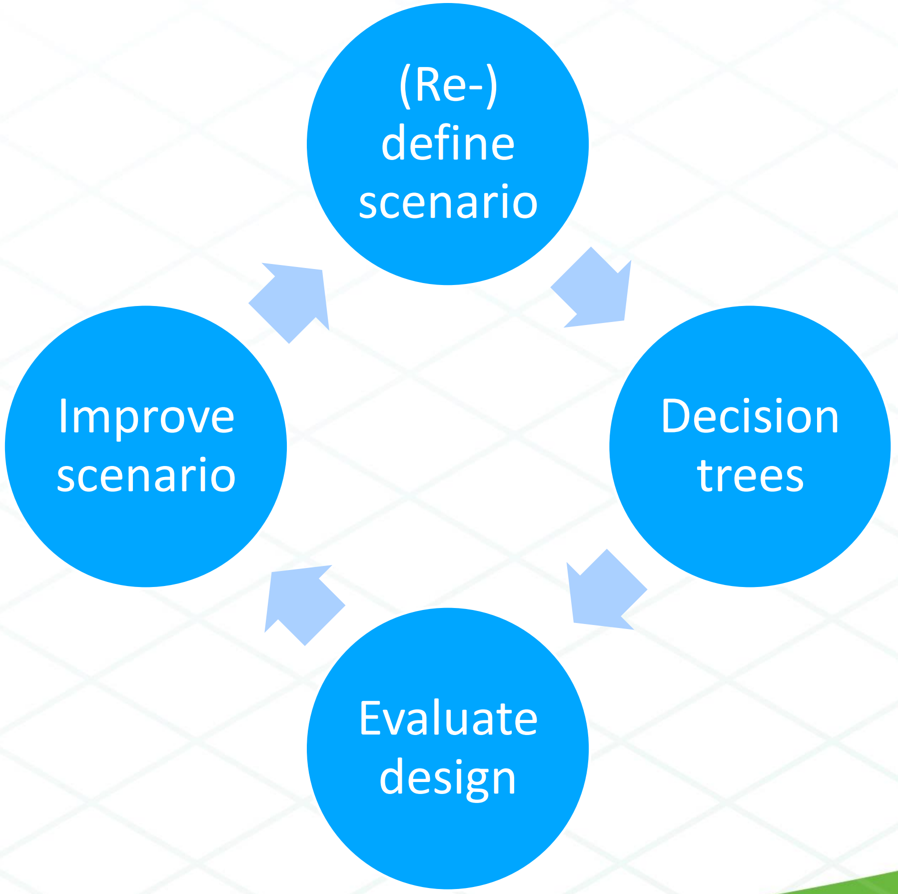
- **Select** the most valuable **system** based on the input of the partners
- Most important results
  - Main technical design decisions
  - Location(s)

MCA approach

- Pitch of four GROHW **system designs**
- Evaluation based on **criteria** and **weighing factors**
- **System design selection**

How did we design the systems?

- Scenario
  - Which ‘perspective’ (+ choices based on this)
  - Location (+ its characteristics)
  - Which consumers (+ profiles)



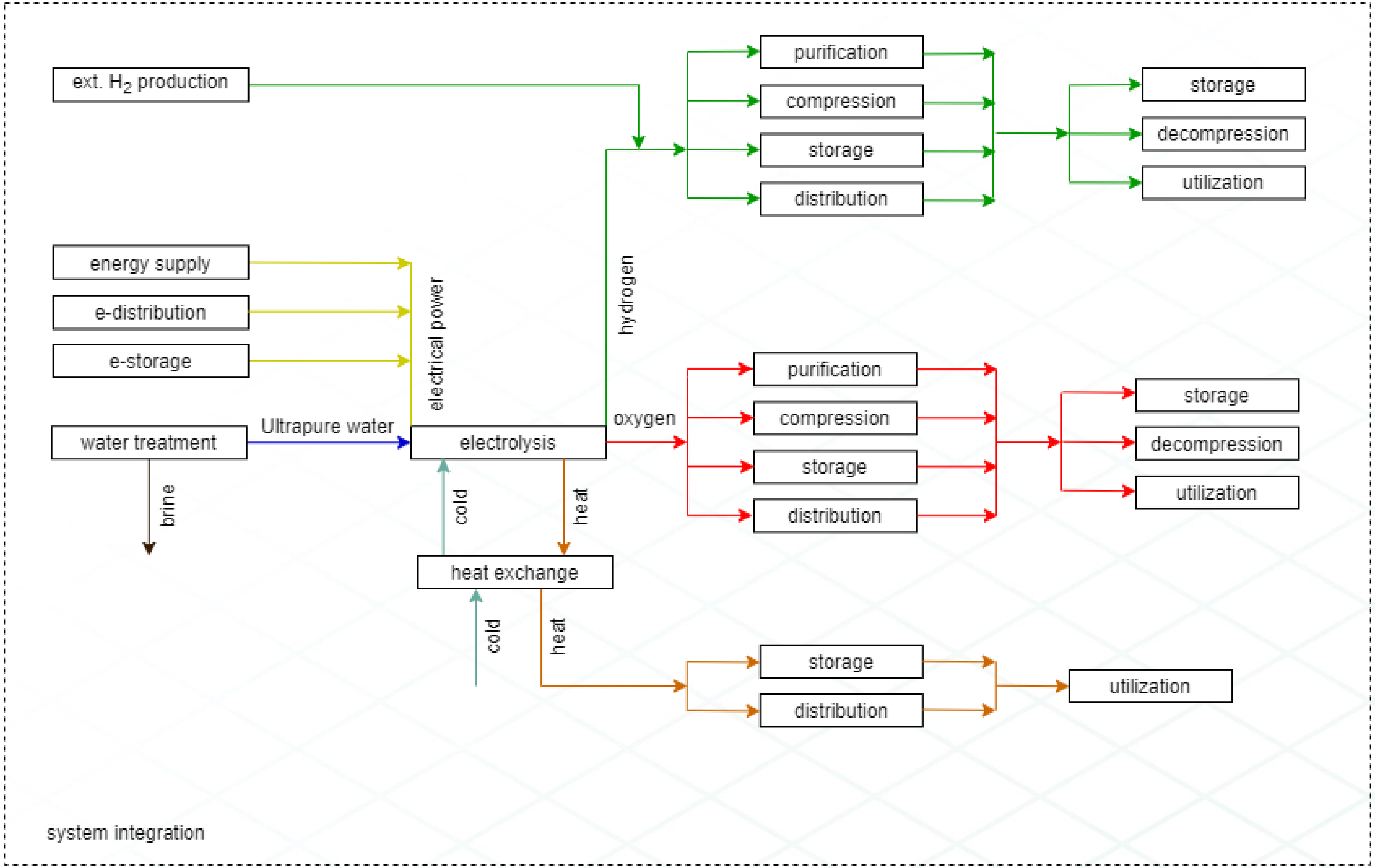
Scenarios

1. **Perspective: economical**
   Location: Central production at S\Park
   Focus: Low costs (CAPEX and OPEX)

2. **Perspective: Sustainable**
   Decetral production at ACS, Nefit Industrial and A1
   Focus: Integration of sustainable energy production and utilising oxygen

3. **Perspective : Security of supply**
   Location: S\Park and A1
   Focus: Delivering hydrogen

4. **Perspective: Flexible (modular)**
   Location: S\Park and A1
   Focus: Future proof


ext. H_2 production
purification
compression
storage
distribution
storage
decompression
utilization
energy supply
e-distribution
e-storage
electrical power
hydrogen
water treatment
Ultrapure water
electrolysis
oxygen
purification
compression
storage
distribution
storage
decompression
utilization
brine
cold
heat
heat exchange
cold
heat
storage
distribution
utilization
system integration

Part 1 – the criteria

CRITERIA	Unit/Definition
Cash	Initial / absolute total investment (CAPEX)
Costs	(CAPEX+10 yrs OPEX) / yearly H_2 production in kg
Operability	Complexity operational phase
Sustainability in CO2	$kgCO_2$ production / kgH_2 produced
Sustainability in SDP	SDP/DOP principles rating

Evaluation matrix

CRITERIA	Unit/Definition	Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
Cash	Initial / absolute total investment (CAPEX)	< 2 Mio €	2 - 5 Mio €	5 - 10 Mio €	10 - 25 Mio €	> 25 Mio €
Costs	(CAPEX+10 yrs OPEX) / yearly H_2 production in kg	< 1 €/kg H_2	1- 5 €/kg H2	5- 12 €/kg H2	12- 20 €/kg H2	> 20 €/kg H2
Operability	Complexity operational phase	Easy to operate, no/very limited operational staff needed	Easy to operate	Average	Complex	Very complex
Sustainability CO_2 emissions	Avoided CO_2 emission/average avoided CO_2 emissions	>5% higher avoided emissions/ average avoided emissions	1-5% higher avoided emissions/ average avoided emissions	Average avoided emissions/ average avoided emissions	1-5% lower avoided emissions/ average avoided emissions	>5% lower avoided emissions/ average avoided emissions
Sustainability Design principles	Felixble and/or multi-functional	Both flexible and multi-functional	Flexible or multifunctional	Nothing specific on this criterion	It's hard to change the system in the future or has only one function	System serves only one function and is nearly impossible to change

1. Cash – absolute initial CAPEX

Defined as:

Total CAPEX / initial investment

Expenditures are related to the costs that are made initially. This represents the cash that is needed before the system is started up.

note: a large-scale variant with relative low cost per kg of H_2 may rate positive on that aspect, but it may be hard to find investors for the total amount, so it may reduce the success rate probability

Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
< 2 Mio €	**2 - 5** Mio €	**5 - 10** Mio €	**10 - 25** Mio €	**> 25** Mio €

2. Costs - CAPEX+10 yrs OPEX (simplified) per kg H_2 per year

Defined as:

- CAPEX
- OPEX (Includes fuel costs and additional operational costs related to production but also costs that return every year even if production is zero)

This is expressed in cost per produced kg of H_2 per year

note: a variant with lower yearly production hours may rate different from a variant with a full time production

Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
< 1 €/kg H_2	**1- 5** €/kg H2	5- 12 €/kg H2	12- 20 €/kg H2	> 20 €/kg H2

3. Operability - Complexity operational phase

Defined as:

Ease to operate / complexity of the system.

- A very simple system, with less components/process blocks and barely not requiring operational efforts (labor) to produce is seen as "less complex"
- A very extended system, with many components/process blocks, heavily interconnected and/or integrated with eachother, and requiring substantial operational efforts and/or highly skilled staff, is seen as "very complex"

The MCA team is to compare and judge/rate the variants accordingly by comparing these.

Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
Easy to operate, no/very limited operational staff needed	Easy to operate	Average	Complex	Very complex

4. Sustainability – Avoided CO_2 emission in Deventer

Defined as:

The amount of CO_2 emissions that is avoided compared to the use of natural gas and diesel. It is expressed as a relative difference with the average of all scenarios.

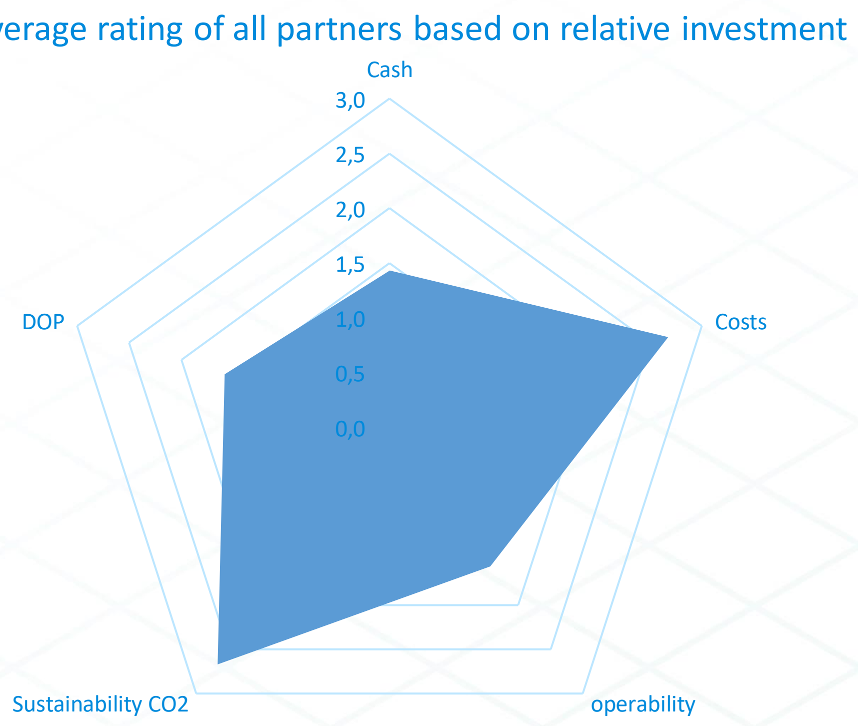
Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
>5% higher avoided emissions/ average avoided emissions	**1-5% higher** avoided emissions/ average avoided emissions	**Average** avoided emissions/ average avoided emissions	**1-5% lower** avoided emissions/ average avoided emissions	**>5% lower** avoided emissions/ average avoided emissions

5. Sustainability - Sustainable Design Principles (SDP / DOP)

1. Flexible design – robust, adaptable and resilient designs
2. Multi-functional design – more functions, more benefits

Very positive judgement 5	Positive judgement 4	Neutral judgement 3	Negative judgement 2	Very negative judgement 1
Both flexible and multi-functional	Flexible or multifunctional	Nothing specific on this criterion	It's hard to change the system in the future or has only one function	System serves only one function and is nearly impossible to change

Rated criteria



Part 2 – the design options / scenarios

Scenario: economical

Scenario: sustainable

Scenario: security of supply

Scenario: flexible

Scenario: economical
Legend
Elektrolyser
Type
Power
Operational hours
Hydrogen gas station
Peak shaving
Transport by pipe
Transport by truck
Hydrogen fueled vehicles
GROHW
ACS
16%
NEFIT
VOS
Alkaline
3 MW
8000 hrs
S/PARK
VAN DORP
auping
A1 Bedrijvenpark Deventer

Scenario: economical

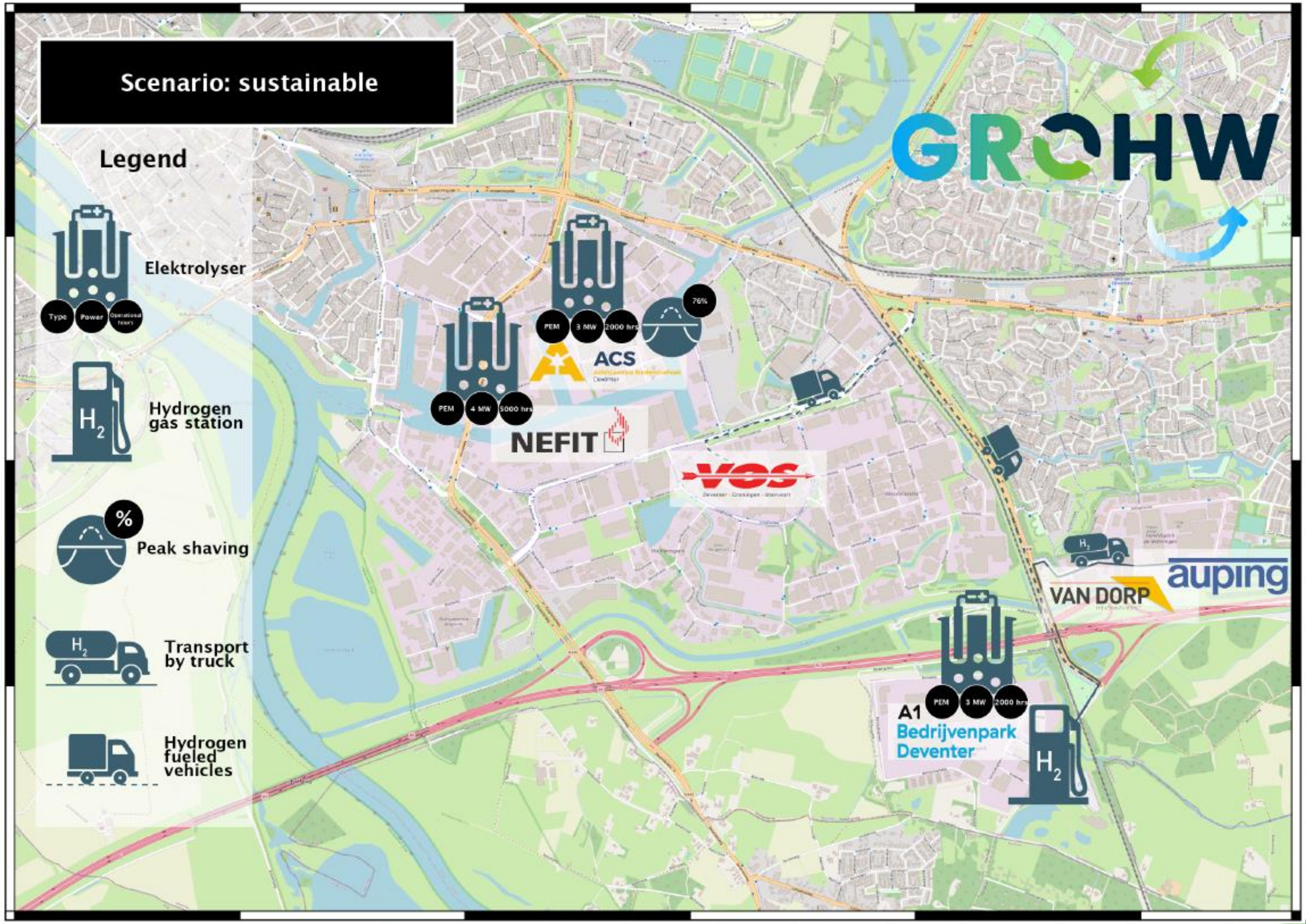
Main characteristics

- Central production at S\Park
- Peak shave burner gas demand profile ACS (16% of H_2 delivered)
- 3 MW ALK 8000 hours
- Use existing e-infrastructure
- No O_2 utilized
- No electrical storage
- Electricity from the grid

Scenario: economical

Preliminary results

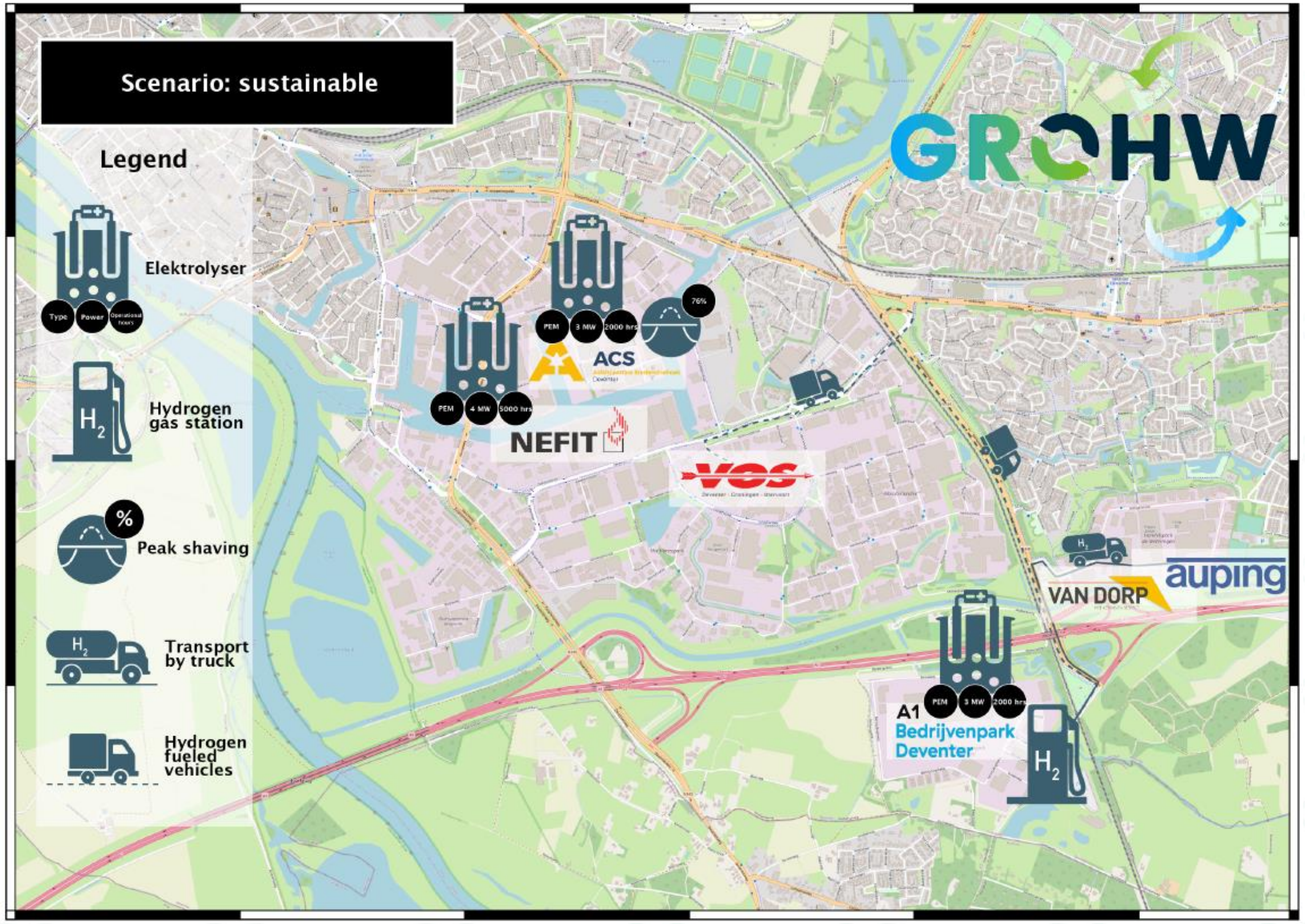
- Low CAPEX because of only one 3 MW electrolyser
- 8000 operating hours means little flexibility in operation


Scenario: sustainable
Legend
Elektrolyser
Type
Power
Operational hours
Hydrogen gas station
Peak shaving
Transport by truck
Hydrogen fueled vehicles
GROHW
PEM
3 MW
2000 hrs
76%
ACS
PEM
4 MW
5000 hrs
NEFIT
VOS
VAN DORP
auping
PEM
3 MW
2000 hrs
A1
Bedrijvenpark
Deventer

Scenario: sustainable

Main characteristics

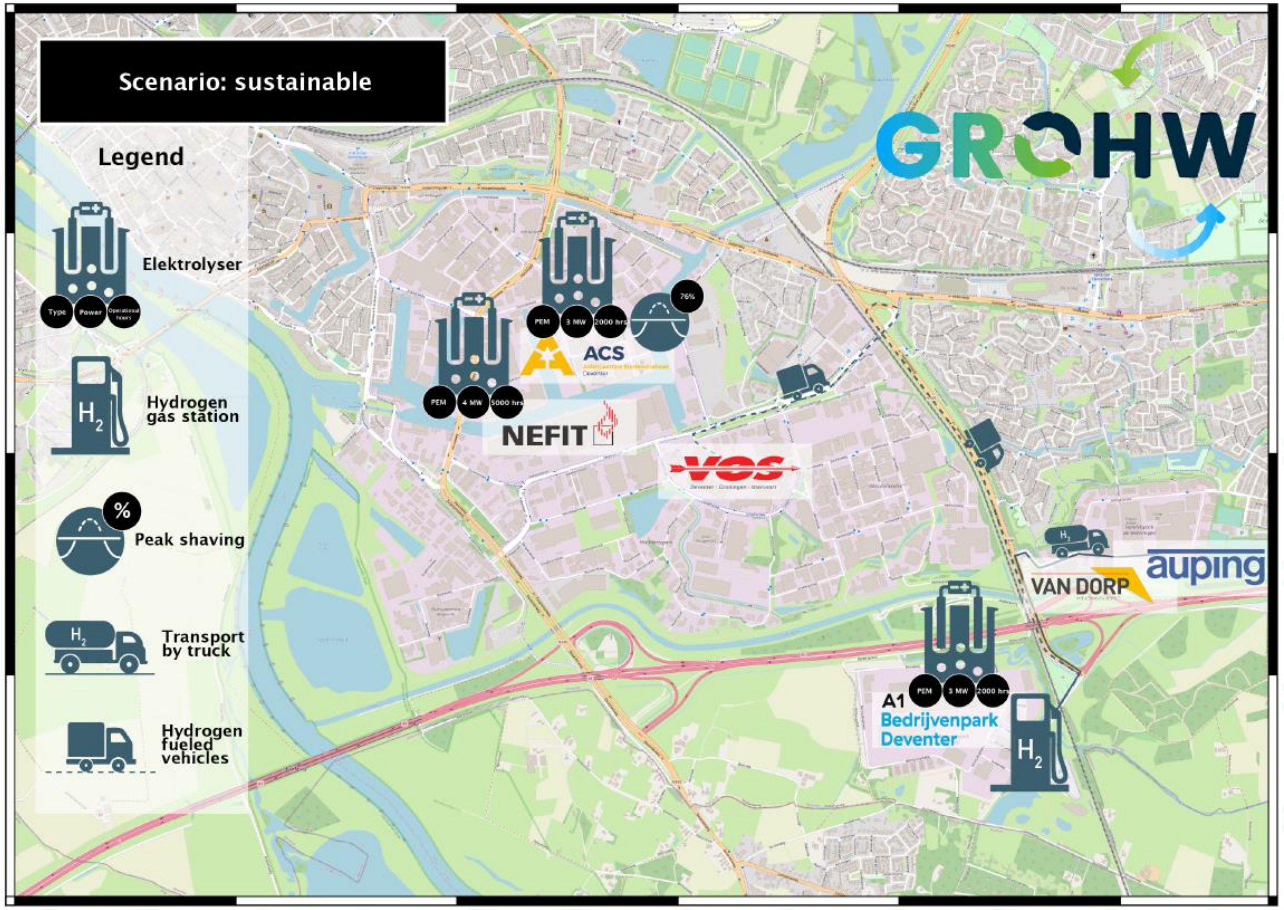
- Decentral production at Nefit, ACS and A1
- Energy from sustainable sources
- Peak shave ACS (76% of H_2 delivered)
- 4MW PEM 5000 hours at Nefit with green certificates
- 3MW PEM 2000 hours at ACS and A1
- O_2 utilized at Nefit and ACS
- Additional storage at ACS required

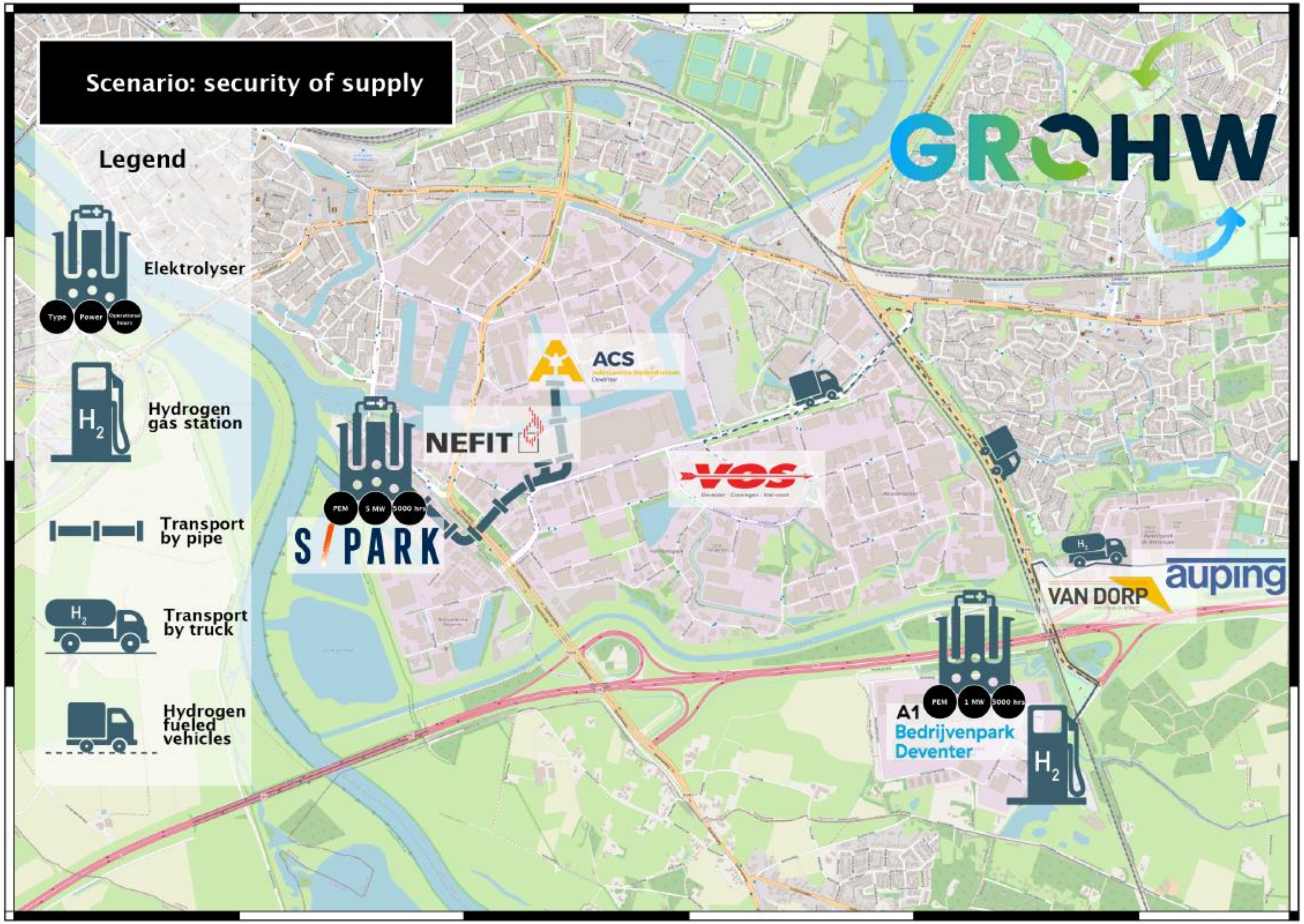


Scenario: sustainable

Preliminary results

- Most sustainable choice
- High CAPEX because of 3 electrolysers
- Little operating hours because of sustainable energy use
- Hard to operate because there's little to control supply and demand



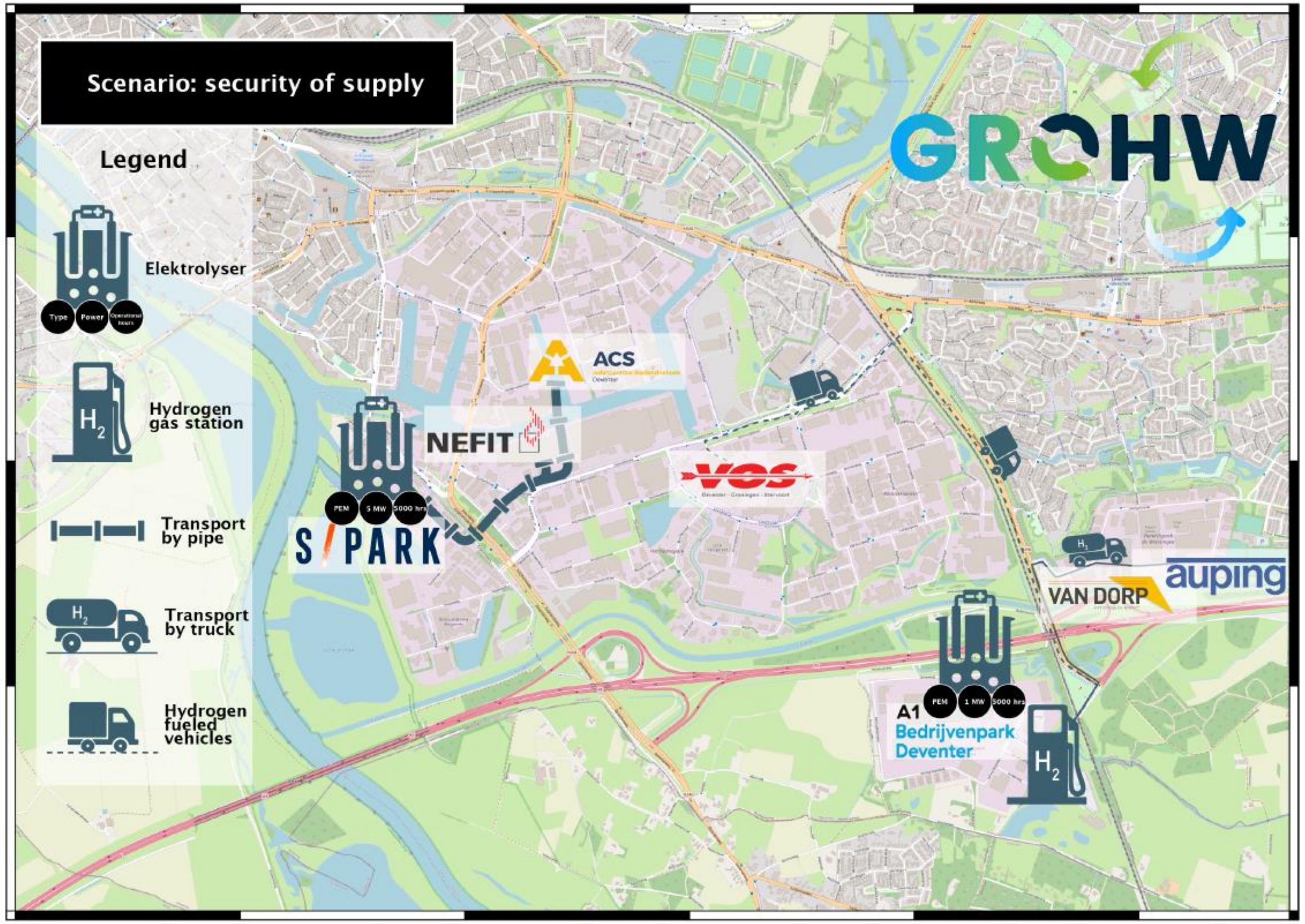


Scenario: security of supply
Legend
Elektrolyser
Type
Power
Operational hours
Hydrogen gas station
Transport by pipe
Transport by truck
Hydrogen fueled vehicles
GROHW
ACS
NEFIT
VOS
PEM
5 MW
5000 hrs
SPARK
VAN DORP
auping
PEM
1 MW
5000 hrs
A1 Bedrijvenpark Deventer

Scenario: security of supply

Main characteristics

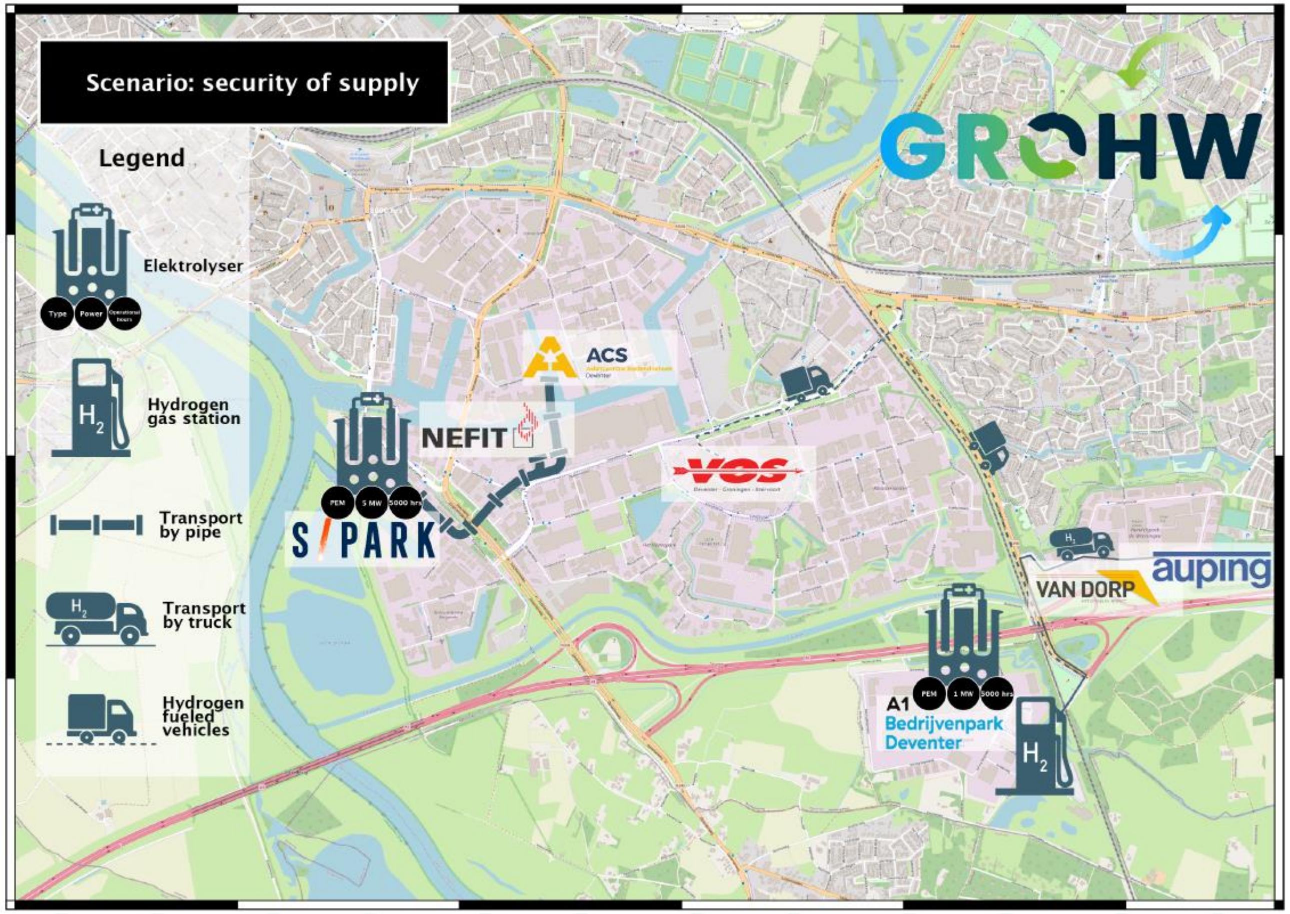
- Decentral production at S\Park and A1
- 5 MW PEM 5000 hours at S\Park
- 1 MW PEM 5000 hours at A1
- 3 MW PEM 2000/5000 at A1 (future)
- Possible O_2 utilization (future)
- Flexible power (future)
- H_2 demand is fulfilled



Scenario: security of supply

Preliminary results

- 5000 operating hours means flexibility in operation and medium CAPEX
- One large hub at S\Park and one small hub at A1



Scenario: flexible
Legend
Elektrolyser
Type
Power
Hydrogen gas station
Transport by pipe
Transport by truck
Hydrogen fueled vehicles
GROHW
ACS
NEFIT
VOS
PEM
5 MW
5000 hrs
S PARK
VAN DORP
auping
PEM
3 MW
2000 hrs
A1 Bedrijvenpark Deventer

Scenario: flexible

Main characteristics

- Decentral production at S\Park and A1, energy from the grid
- 5 MW PEM 5000 hours at S\Park
- 3 MW PEM 2000 hours at A1
- O_2 utilization possible

Scenario: flexible

Preliminary results

- Compared to security of supply, the electrolyser at A1 has less operating hours but more power
- Total of 7 MW increases costs

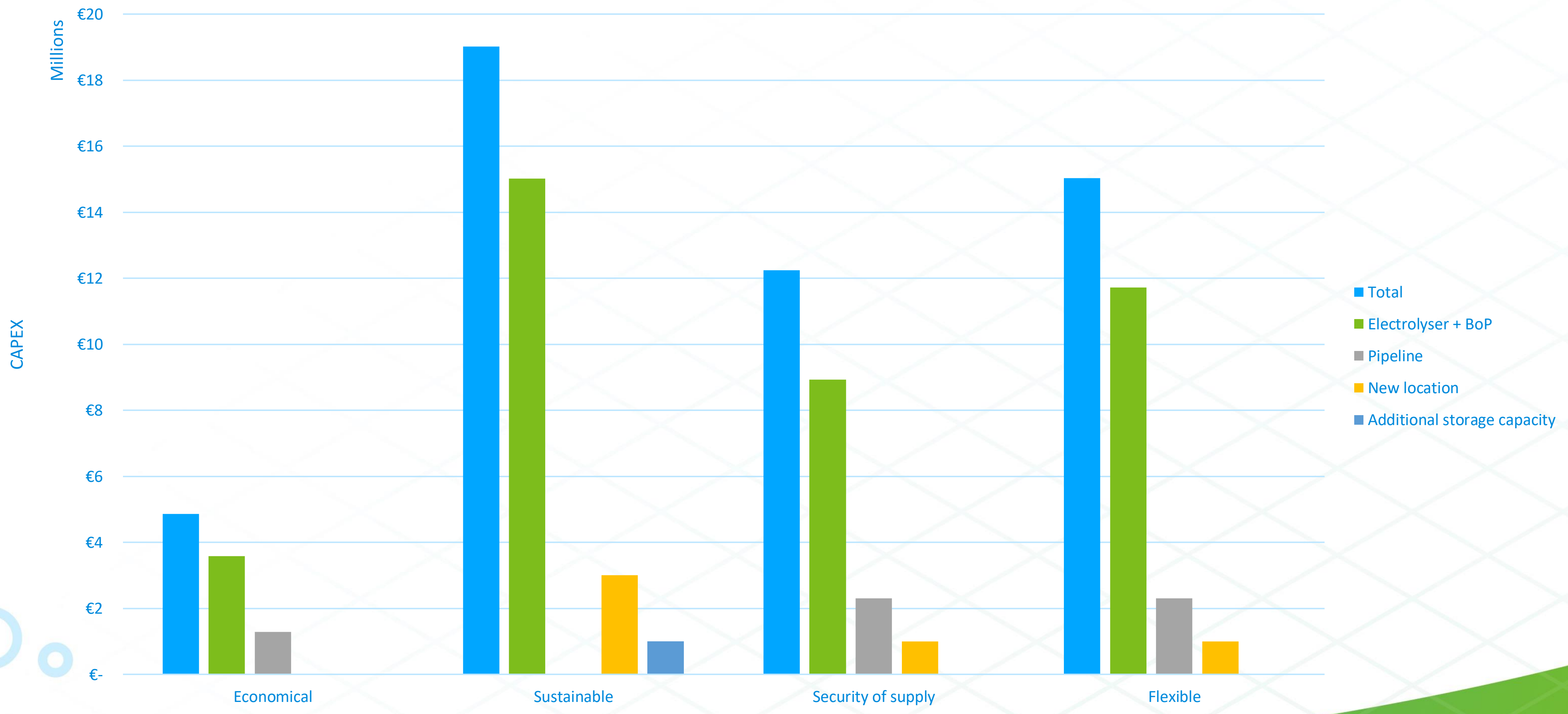
Part 3 – Results and discussion

- Cash evaluation
- Costs evaluation
- Operability
- Results
- Discussion

Included CAPEX

- Electrolyser
  - 1100 €/kW for 5 MW PEM, 2020
  - 962 €/kW for 2 MW ALK, 2020
  - +30% for balance of plant (compression, purification and engineering)
  - 1 million EUR for additional (compared to other scenario's) storage at ACS in sustainable scenario. Exact costs to be determined in next phase
  - 40% of total cost has economies of scale, with a scaling factor of 0,7
- Hydrogen pipeline (plastic pipeline)
  - 1712 €/m below sealed surfaces
  - 880 €/m below greenfield
  - 40% of the CAPEX is returned after 10 years (at 3% discount rate)
  - OPEX is negligible
- New location
  - 1 million € for electrical connection, permitting, safety and setting up organization

CAPEX per scenario



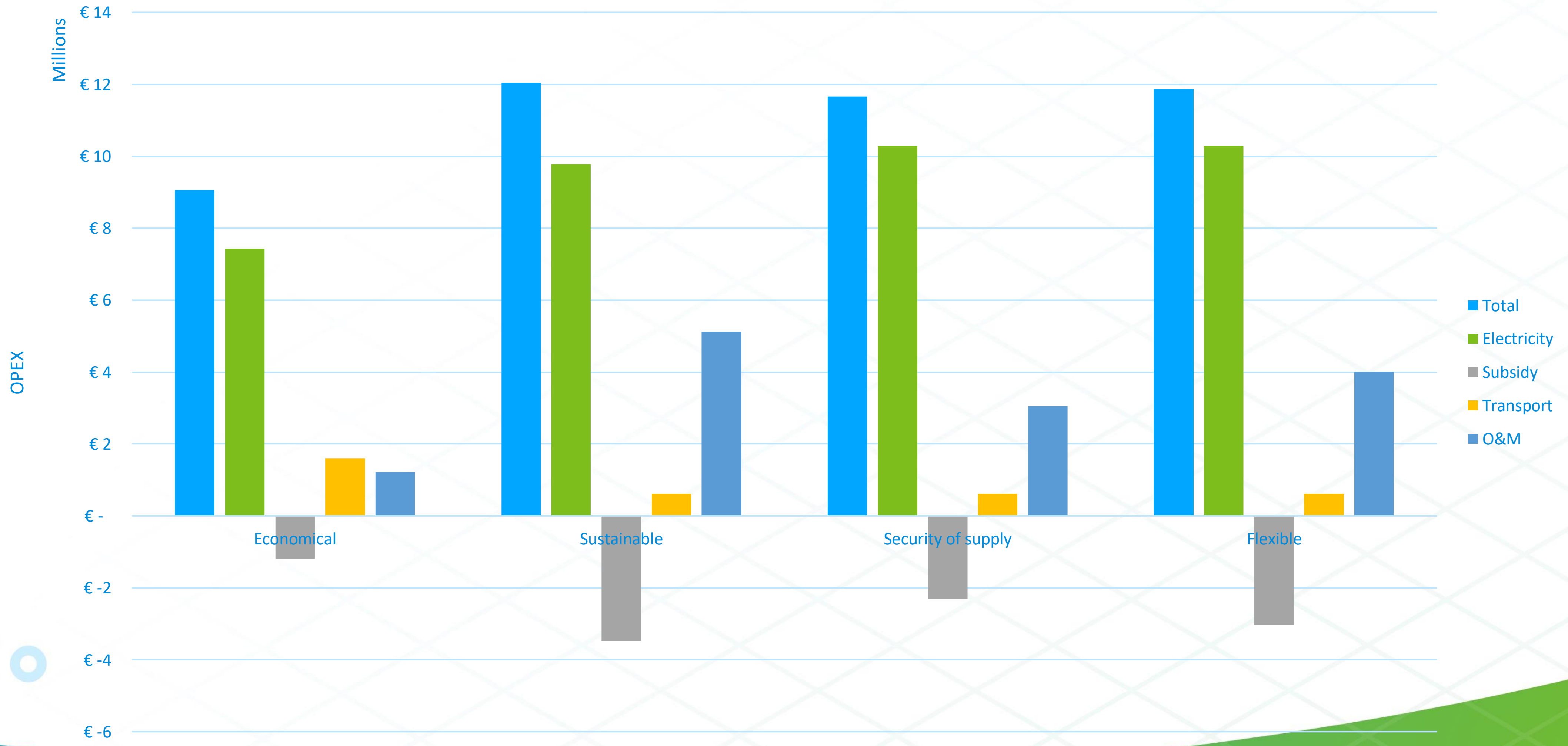
Included OPEX (1)

- Electricity for hydrogen production
  - 42 EUR/MWh for electricity from the grid
  - 2 EUR/MWh for green certificates
  - Alkaline is 80% efficient, PEM is 70% efficient
  - +5% auxiliary power consumption (i.e. compression, cooling)
- Subsidy
  - 150 EUR/ton CO_2
  - For 2330 full hours a year
  - Avoided CO_2 emission is based on avoided natural gas and diesel consumption with same efficiency
- Transport
  - By road: 13 480 EUR/ton hydrogen per year

Included OPEX (2)

- Maintenance en operation
  - 4% of electrolyser CAPEX
- Lifetime of 10 years
- Discount rate of 3%

OPEX per scenario for 10 years



CAPEX, OPEX and production

Scenario	CAPEX (millions)	CAPEX + 10 years OPEX (millions)	Annual hydrogen production (ton)	Production cost (per kg H2)
Economical	€ 5	€ 14	429	€ 3,16
Sustainable	€ 19	€ 31	496	€ 6,26
Security of supply	€ 12	€ 23	523	€ 4,44
Flexible	€ 15	€ 26	523	€ 5,02

Operability

- Economical is rated complex because of little flexiblity in operation (8000 hours are needed)
- Sustainable is rated is very complex because we aim to use as much sustainable energy as possible. Therefore the supply is not in our control
- Security of supply is rated as average because there are no notable positives or negatives
- Flexible is rated as easy to operate because of the low amount of needed operating hours at A1 (2000 hours) in combination with demand driven production

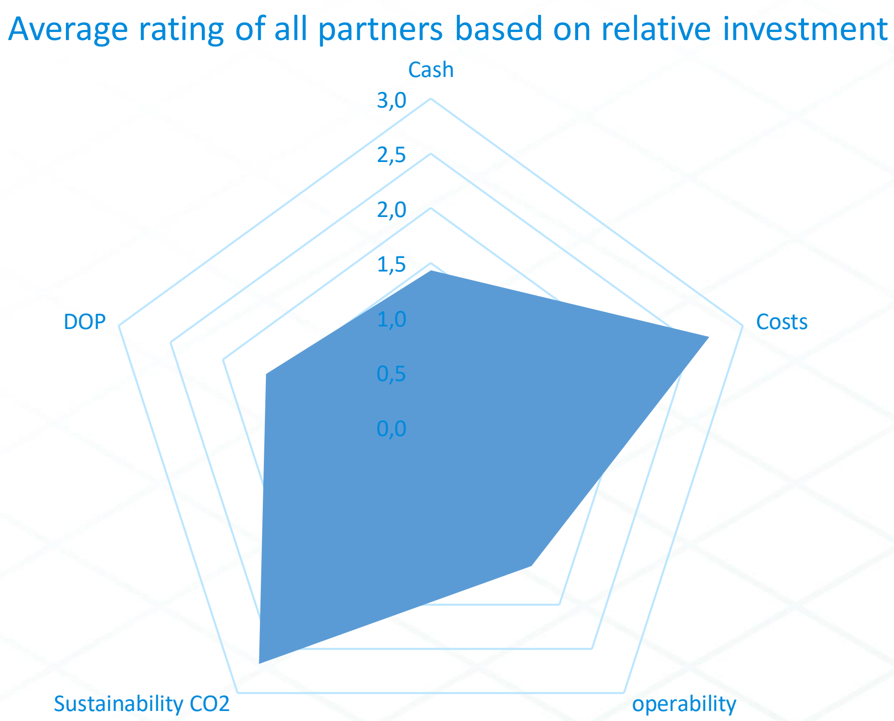
Results (1)

Criteria	Economical	Sustainable	Security of Supply	Flexible
Cash	€ 5	€ 19	€ 12	€ 15
Costs (per kg H2)	€ 3,16	€ 6,26	€ 4,44	€ 5,02
Operability	Complex	Very complex	Average	Easy
Sustainability – CO_2 emissions	-13%	+1%	+6%	+6%
Sustainability - design principles	System serves only one function and is nearly impossible to change	Both flexible and multi-functional	It's hard to change the system in the future or has only one function	Flexible (not multifunctional)

Results (2)

CRITERIA	WEIGHT	Impact on total	Unweighted score			
			Economical	Sustainable	Security of supply	Flexible
1. Cash	1,43	14%	3	2	3	2
2. Production Cost	2,68	27%	4	3	4	3
3. Operability	1,57	16%	2	1	3	4
4. Sustainability - CO2 emissions	2,67	27%	1	4	5	5
5. Sustainability - Design principles	1,58	16%	1	5	2	4
	10	1	11	15	17	18
			RANK 4	RANK 3	RANK 2	RANK 1

Rated criteria



Results (3)

			Weighted score			
CRITERIA	WEIGHT	Impact on total	Economical	Sustainable	Security of supply	Flexible
1. Cash	1,43	12%	*0,35*	*0,23*	*0,35*	*0,23*
2. Production Cost	5,00	41%	*1,63*	*1,22*	*1,63*	*1,22*
3. Operability	1,57	13%	*0,26*	*0,13*	*0,38*	*0,51*
CO2 emissions	2,67	22%	*0,22*	*0,87*	*1,09*	*1,09*
5. SDP	1,58	13%	*0,13*	*0,65*	*0,26*	*0,52*
	12	1	2,6	3,1	3,7	3,6
			RANK 4	RANK 3	RANK 1	RANK 2

Identified possible game changers	Economical	Sustainable	Security of supply	Flexible
Oxygen use		- Cash, +production cost		- Cash, +production cost
Stack replacement	+ production cost		- production cost	
+sustainability		+ sustainable		+ sustainable
flex (TSO/(DSO in the future))		+++ production cost	+ production cost	++ production cost

During the session a higher weight was given to production costs

Conclusions & path forward

- Team concludes a hybride variant as best-value option
- Start with **security of supply** design as basis which can in time move to **flexible** design
- Make the **security of supply** design future proof by keeping options open for:
  - Oxygen utilisation
  - Extension at A1 from 1 MW to 3 MW
  - Flexible power input (TSO/DSO)

Calculation for CO2 emissions

CO2 emission					
	Economical	Sustainable	Security of supply	Flexible	unit
CO2 emission at production	0	0	0	0	kg/y/tH2
Avoided CO2 mission natural gas	2684	3166	3356	3356	ton/y
Avoided CO2 emission diesel	503	503	503	503	ton/y
Total avoided CO2 emission	3187	3670	3859	3859	ton/y
Avoided CO2 at S\Park	3187	0	3030	3030	ton/y
Avoided CO2 at A1	0	830	830	830	ton/y
Avoided CO2 at Nefit	0	2234	0	0	ton/y
Avoided CO2 at ACS	0	606	0	0	ton/y
Avoided CO2 at S\Park	139249	0	211777	211777	ton/y
Avoided CO2 at A1	0	144979	57992	144979	ton/y
Avoided CO2 at Nefit	0	156125	0	0	ton/y
Avoided CO2 at ACS	0	105971	0	0	ton/y
Net CO2 emission	-3187	-3670	-3859	-3859	ton/y
Net CO2 emission as percentage of average	***87%***	***101%***	***106%***	***106%***	

VII

APPENDIX: GROHW STARTING POINTS MTSA

TECHNOPOWER

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Report

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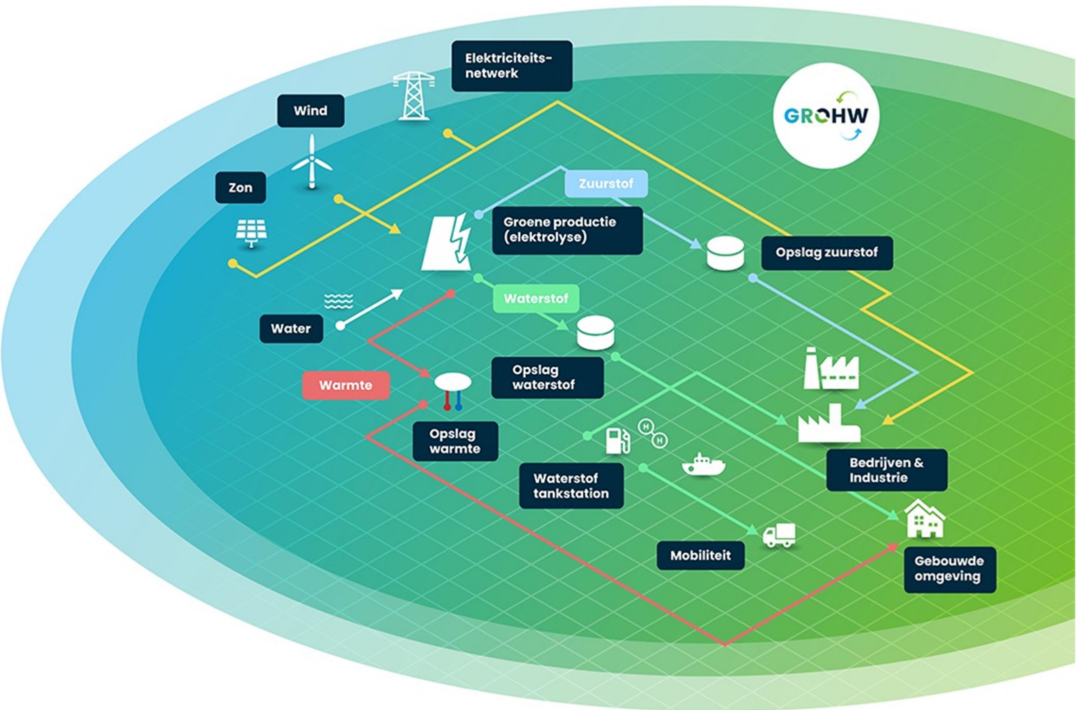
Revision / Date	:	2 / 27-05-2021
Principal	:	
Author	:	T.R. Kruijk
Project no.	:	1900601R
E-mail address	:	timon.kruijk@mtsa.nl

Starting points GROHW

Work Package 3



MTSA TECHNOPOWER

Table of contents

1. Goal of the project

Under the lead of Witteveen+Bos a scenario will be drafted to create a hydrogen hub in the city of Deventer (WP2). For this, one or more separate locations in and near the city will be selected where electrolysers could be placed. The end users of hydrogen will be different for each location and they are to be specified at a later stage. As a first estimate, this will concern 5 MW of electrolysers to be used near the Asfalt Centrale (AsfaltNu, AND) and a 2 MW electrolyser on the location A1. At AND the hydrogen will be used for combustion, whereas at A1 it will be used for a hydrogen fuel station. This is a first estimate, which at the time of publishing has become uncertain. However, the order of magnitude is correct and hence, this estimate will be assumed for the time being.

For this Work Package, a Basic Design Study will be carried out by MTSA, which has the main purpose to generate the following technical documentation:

- System specifications;
- ISBL/OSBL/utilities;
- PFD;
- Lay-out;
- Planning realisation phase;
- Cost calculation of 10% accuracy for the initial unit;
- Cost calculation of 25% accuracy for units in serial production.

2. General scope

2.1. Scope description

The scope of this WP concerns the (process) equipment that is required for converting drinking water to hydrogen and oxygen using PEM electrolysis and to treat the hydrogen in such a way to make it suitable for its usage at each location. This includes at least:

- Electrolysis stacks;
- Equipment for filtering and treating drinking water to UPW (ultrapure water);
- Equipment for circulating and cooling UPW over the stacks and separating UPW and oxygen;
- Equipment for treating UPW which is circulated over the stacks, in order to remove impurities;
- Equipment for removing hydrogen from the stacks and treating it for its different purposes;
- Low pressure buffer vessel for hydrogen;
- Compressor(s) for compressing hydrogen to a certain pressure;
- High pressure storage for hydrogen;
- Equipment for cooling UPW from a relatively high to a slightly lower temperature (cooling cycle 1);
- Equipment for cooling back cooling water from a relatively medium to low temperature and supplying this to several applications within the electrolyser (cooling cycle 2);
- Equipment for transforming and rectifying the supplied electrical power in order to make it suitable for application in an electrolysis stack;
- Various vessels, including amongst others supply vessels and process vessels (e.g. gas-liquid separators);
- Equipment (e.g. pumps, heat exchangers, filters);
- Piping, filters, (control) valves, etc. to connect all equipment;
- Instrumentation to monitor and control the process and make sure that it operates in a safe manner;
- Control system for the installation as described in this document, which can communicate with the overall control system on site.

The following is not part of the scope:

- Equipment for any further treatment of oxygen;
- Equipment for supplying hydrogen to a hydrogen fuel station;
- Piping to transport the various gasses to the end user(s);

- Equipment for cooling back the heated cooling water from cooling cycle 1 (as this can possibly be used for other applications that require heat);
- Supply of utilities;
- Back-up power supply in case of a power failure;
- Battery package for temporary storage of electrical power, in case this turns out to be required.

All boundaries with the surrounding system are schematically shown in a work breakdown structure made by Witteveen+Bos, attached in Appendix I. In chapter 3 the system itself and its boundaries will be discussed in detail. For this, the reader is referred to the components mentioned on the schematic overview of the installation which will be designed by MTSA. This overview has been attached in Appendix II.

2.2. Terminology

In this document, several technical terms are used. In order to clarify this, a brief explanation is given in this paragraph.

An *electrolysis stack* or *stack* is the heart of the process. This is the main component in which water is separated into oxygen and hydrogen.

An *electrolyser* is an installation which is built around one or more electrolysis stacks, but which also includes all surrounding equipment required to properly operate the(se) stack(s) such as water treatment, power electronics, separation vessels, cooling loops, pumps, hydrogen treatment, etc.

A *compressor* is a component in which a gas is compressed from a lower to a higher pressure. The composition of the gas is not changed within the compressor, nor is the compressor part of an electrolyser.

3. Detailed scope and starting points

3.1. Modularity / size of the system

As the exact location of the installation has not yet been determined, the size of the final installation is not yet known. However, it is the purpose of this project to develop a system that can be applied in a modular way such that it can be fitted to applications of different sizes. Because of the scale that has been studied during this project so far, it has been chosen to develop elektrolyser modules of 1 and 2 MW, which can be added together to obtain systems of higher capacities. For example, an electrolyser system of 5 MW can be obtained by adding two modules of 2 MW and one module of 1 MW. This modularity allows MTSA to design an electrolyser (module) without requiring the exact size of the final system(s).

Modularity also applies to components within the system, such as the treatment of hydrogen. The quality required at a certain location determines which kind of hydrogen treatment is required. A few options have been included in the schematic overview in the appendices (1900601R-007). Hydrogen after treatment is further elaborated upon in paragraph 3.3.5. The same principle applies to compression and storage. This is further elaborated upon in paragraph 3.3.6.

3.2. Boundaries and contents of installation

3.2.1. Boundaries and interfaces with other installations

The electrolyser installation should be connected to various utility systems, supply pipes for water, nitrogen and compressed air, delivery pipes for hydrogen and oxygen and drains for concentrate. These utilities, products, by-products and other connections are further elaborated upon in the paragraphs below.

The following utilities are required:
- Electricity, for generating hydrogen and running the system;
- Instrument air / compressed air, to operate pneumatically actuated valves;
- Nitrogen, for purging the system;
- Drinking water, for making UPW;
- Cooling water, to cool UPW, oxygen and hydrogen;
- Drain(s), for releasing by-products.

The boundaries of the installation are formed by the last valve or flange before the process equipment in the supply lines of utilities. For operating the various electrical components and for providing adequate control to the installation, the required power electronics as well as a control cabinet is supplied. These will be placed in a separate part of the installation. For each module, one electrical connection is required, for which a connection point is available in the installation. Cabling towards this point is not included in the scope of MTSA. The control system operates the MTSA installation autonomously depending on the (expected) power input, which will be determined in the overall control system by Witteveen+Bos.

The capacities and process parameters of the utilities are described in paragraph 3.2.4.

3.2.2. Specification of products, by-products and in-between products

The following products are produced within the electrolyser installation:

Hydrogen
Pressure: max. 37 bar(g)
Temperature: 20 °C

Oxygen
Pressure: max. 6 bar(g)
Temperature: 20 °C
Water contents: saturated

The mentioned conditions concern gas data when the gas is leaving the *electrolyser* (please refer to the terminology list in 2.2). At the various locations the gasses are used and processed in a different way and this results in a different gas quality and storage pressure at each location. The treatment of oxygen is not part of MTSA's scope and is therefore not considered in this document. It is assumed that the oxygen will be used for other applications, but in case no end user is available the oxygen is still produced when the electrolyser is running. In that case it needs to be vented to the atmosphere, but deciding which way the oxygen goes and how to direct it there is not within the scope of MTSA.

Hydrogen treatment at each location is included within MTSA's scope and depends on the requested quality by the end users of the gas. Based on the first estimate, the following can be stated:

At AND
Pressure: low (few bar), to be reduced to a few mbar just before entering the furnaces
Water content: no condensation may take place at a temperature of -15 °C
Quality: no other requirements

At A1
Pressure: high (e.g. 350 or 500 bar(g))
Water content: max. 5 ppmV
Quality: Grade D according to ISO 14687-2

Different end users at one location may require different qualities of hydrogen, but this is not taken into account. An electrolyser at one location will produce hydrogen of a certain quality and this will be (compressed and) stored in one vessel. In case multiple hydrogen qualities are required on one site, this is possible but this is not an option that is considered within the scope of this WP.

Besides hydrogen and oxygen there is one by-product, which is to be drained to the local sewage system:

Concentrate (from water treatment installation)
Exact composition to be determined. This water is assumed to contain no chemicals and only contain impurities that are present within drinking water, albeit with a higher concentration.

3.2.3. Specification of resources and excipients

For performing the different steps of the process, several resources and excipients are required. At this stage, exact details are not yet known and they will be clarified in a later stage. It is assumed some of these resources will need to be available on site for direct usage and that a small storage room for them is available close to the installation.

3.2.4. Specification of utilities

Supplying the utilities is not part of the scope of MTSA. Witteveen+Bos takes care of the OSBL-scope of MTSA to within 1 meter of the MTSA-installation. MTSA will take care of the connection to her own installation. The following utilities are required. It should be noted that these are first estimates and that these are subject to alteration:

- **Electricity:**
  The main connection will be used for both the electrolysis itself and for feeding the different components in the installation. For this, the following estimations have been made, per module size:
  1MW – 1,1 MVA for electrolysis, plus the electricity required for the electrical equipment within the installation;
  2MW – 2,2 MVA for electrolysis, plus the electricity required for the electrical equipment within the installation.
  The installation should be connected to the 10 kV grid
- **Instrument air / compressed air:**
  The installation contains several valves which are operated using instrument air. The exact usage of instrument air / compressed air is to be determined in a later stage of the engineering process.
- **Nitrogen:**
  The hydrogen part of the installation will sometimes need to be purged, depending on the usage profile of the electrolyser. In case of emergency, purging is also required. The required amount and quality of nitrogen will be defined at a later stage.
- **Drinking water:**
  Within the installation, drinking water is filtered to UPW with a conductivity of $<0,055$ µS/cm. During this process some water is lost as concentrate. In the heart of the process, water is used for the conversion into O_2 and H_2.
- **Cooling water:**
  Cooling water is used within the installation to remove excess heat which is brought into the UPW during the electrolysis process. The cooling water is returned with a higher temperature. Cooling back the cooling water to the original temperature is not within the scope of MTSA, but it is assumed that the cooling water will always be supplied within the requested temperature range. A temperature sensor (and alarm) which monitor the temperature of the supplied cooling water is included in the scope of MTSA.

3.3. Starting points per step

3.3.1. Supply water treatment system

The supply water treatment system (S-101), in which drinking water is converted to UPW, consists of several steps in which the conductivity of the water is decreased step-by-step to the point where it can be called “ultrapure”. One or more drains will be present, from which concentrate is drained. From this first treatment system the UPW flows into a break tank (V-151), under ambient conditions. After the break tank the water is pumped to the O_2-H_2O separator (V-201), which is operated under pressure.

3.3.2. UPW-circulation over stack(s), H_2 and O_2 production

From the O_2-H_2O separator (V-201), UPW is circulated over the electrolysis stack(s) and hydrogen and oxygen are produced. UPW is fed to the anode side of the electrolysis stack(s). When electrical power is supplied to the stack(s), O_2, H+ ions and electrons are formed at the anode. The O_2 is transported along with the circulating UPW, while the H+ ions and electrons travel to the cathode through the membrane and electrical circuit, respectively, where they combine to form H_2. The formed O_2 goes back to V-201 along with the excess UPW that has not been converted. Most UPW will return to V-201 as it is mainly used to remove excess heat from the stack(s). The UPW flow is kept at a constant temperature by a heat exchanger before the stack(s) inlet(s), in order to ensure that all temperature requirements are complied with. The pressure in this loop is controlled by a back-pressure regulator in the O_2-outlet from V-201, as the pressure in this vessel determines the exit pressure of O_2 from the system.

3.3.3. UPW-treatment in circulation

The UPW in the circulation flow described under 3.3.2 is slowly contaminated, as H_2O is constantly converted to oxygen and hydrogen, but the few impurities that are still present within the flow remain and some impurities can be added because of the contact between UPW and system materials. These accumulate over time and have to be removed from the UPW. Another water treatment system (S-221) is present in the circulation loop to remove these. The conductivity of the UPW in the circulation loop is monitored constantly to ensure that the correct water quality is supplied to the stack(s).

3.3.4. Oxygen

The oxygen which leaves the system from the O_2-H_2O separator has a temperature of max. 70 °C and is saturated with water. As oxygen at this temperature can hold a lot of water, it is worthwhile to recycle this water. For this, a heat exchanger is used, in which the majority of the water condensates. After the heat exchanger, the liquid water is collected and led back to break tank V-151 mentioned in paragraph 3.3.1. The water still contained in the oxygen after this step is considered to be lost.

3.3.5. Hydrogen

Hydrogen is leaving the stack(s) at a pressure of maximum 40 bar(g). This pressure is regulated by a back-pressure regulator at the outlet of the gas treatment installation. During electrolysis, a part of the UPW migrates through the membrane to the cathode-side. This liquid UPW needs to be separated from the hydrogen gas before the gas can be treated any further. This happens in a H_2-H_2O separation vessel (V-301). The separated UPW is transferred back to the O_2-H_2O separator (V-201). Downstream of V-301, hydrogen is further treated to the specifications required. These specifications differ per location. Some possible qualities could be:

- Hydrogen is used for combustion, no special requirements are present. However, it should be avoided that condensation can take place within piping leading to the end user when the outside temperature is low. This means that some water vapour will have to be removed from the hydrogen;
- Hydrogen is used for a hydrogen fuel station. As the requirements for hydrogen in cars are strict, a gas treatment installation will be included in which the hydrogen is cleared from any impurities such as water and oxygen. At the outlet of the installation, the hydrogen fulfills Grade D quality according to the ISO 14687-2 norm:

Characteristics (assay)	Type I, Type II
	Grade D
Hydrogen fuel index (minimum mole fraction) [a]	99,97%
Total non-hydrogen gases	300 µmol/mol
Maximum concentration of individual contaminants	
Water (H_2O)	5 µmol/mol
Total hydrocarbons [b] *(Methane basis)*	2 µmol/mol
Oxygen (O_2)	5 µmol/mol
Helium (He)	300 µmol/mol
Total Nitrogen (N_2) and Argon (Ar) [b]	100 µmol/mol
Carbon dioxide (CO_2)	2 µmol/mol
Carbon monoxide (CO)	0,2 µmol/mol
Total sulfur compounds [c] *(H_2S basis)*	0,004 µmol/mol
Formaldehyde (HCHO)	0,01 µmol/mol
Formic acid (HCOOH)	0,2 µmol/mol
Ammonia (NH_3)	0,1 µmol/mol
Total halogenated compounds [d] *(Halogenate ion basis)*	0,05 µmol/mol
Maximum particulates concentration	1 mg/kg

3.3.6. Compression and storage

After leaving the electrolyser, the hydrogen has the quality required for the specified end user(s). A typical sequence will consist of a low pressure buffer vessel, a compressor and a high pressure storage. However, it depends on the flow- and pressure requirements of the end user to determine which exact components are required. In case the end user(s) only require hydrogen at a pressure lower than e.g. 35 bar(g), it can be chosen to use only a low pressure buffer vessel. In this case a compressor and high pressure storage are not needed, positively affecting the CAPEX cost.

Low pressure buffer vessel

The electrolyser system can cope with a high turn-up/turn-down ratio. This helps with e.g. using peaks in green energy production and taking care of grid stability. However, the production of hydrogen is not constant in such a case. A compressor is sensitive to a varying supply flow and switching a compressor on and off constantly severely affects the lifetime of a compressor. In order to deal with this, a low pressure buffer vessel (V-401) is foreseen. In this vessel, hydrogen is temporarily stored at the outlet pressure of the electrolyser system. A pressure control valve in the electrolyser system keeps the pressure in the electrolyser system constant, independent of the pressure in the buffer vessel. This pressure is lower than the before mentioned stack output pressure of 40 bar(g) due to losses in the downstream hydrogen treatment, but only to a limited extent. The pressure in V-401 is estimated to be maximum ca. 35-37 bar(g).

The exact size of the low pressure buffer vessel depends on the amount of full load hours and the expected fluctuations in hydrogen production, compared to the requirements stated by the end user(s).

Compressor

After the low pressure buffer vessel, hydrogen is compressed to a higher pressure in a compressor (A-411) if the end user(s) require hydrogen at a high pressure. The end pressure differs per location, but in both cases a minimum number of on/off-switches is desired in order to maximize the compressor's lifetime. The capacity of the compressor should be at least equal to the maximum output of the electrolyser, otherwise this would reduce the maximum capacity of the complete system.

High pressure storage

After the compressor the hydrogen is stored in a high pressure storage (V-421). The exact storage pressure and size of the storage differs per location. When a final location is selected, the exact storage size can be determined, as this greatly depends on the demand of the end users attached to this location and how the hydrogen usage profile corresponds with the production profile. The same applies to the storage pressure. The combination of size and pressure also determine what kind of storage is to be used (e.g. bottles, one storage tank, battery of cylinders).

In general, it can be stated that when WP2 is completely finished, the exact storage size and pressure and requirements for the compressor can be defined properly.

3.4. General remarks

3.4.1. Spares

As at the time of writing only a general system lay-out is known, exact details considering the required spare parts is not possible. However, several components of the installation are expected to have several spare parts. These include, but are not limited to:
- UPW installation;
- Pumps;
- Compressor;
- Stack(s).

Once details considering the main components are known, a general list of main spare parts will be set up, though a detailed list of spare parts is included in the scope of this project. It is assumed that a small storage facility for spare parts is available on site.

3.4.2. Equipment and piping

For piping, standard sized DIN/EN 10253 piping is used. Pipe connections are made by flanges according to EN1092. For smaller sizes, tubing is used. For tubing containing hydrogen, Swagelok or equivalent brands will be used.

3.4.3. Location

As mentioned before, a specific location is still to be selected. A first assumption has been made using the data currently available. Any chosen location will have to fulfill the following requirements:
- A license can be obtained for the amount of dangerous gas stored ("Wet milieubeheer");
- Plenty of room is available for the required safety distances. At this stage, it is not possible to give an indication of the plot plan as it greatly depends on the size of the required electrolyser(s), compressor and especially storage;
- A sound emission of a level which is to be defined during a later stage is allowed;
- The location is not situated in an ATEX zoned area.

3.5. Operational starting points

3.5.1. Control

The electrolyser, compressor and storage system operates as an autonomous unit. The electrolyser receives a specific amount of electrical energy and generates an amount of hydrogen by using this. The amount of available electrical power can be determined by several different factors, but this is outside the scope of MTSA and should be determined in the overall control system. The corresponding intake of drinking water, cooling water, nitrogen and compressed air is automatically regulated. Of course, there are some required inputs and resulting outputs of the system as a whole. The required inputs are for example (but not limited to):

- Amount of power available;
- No alarms activated.

The given outputs are for example (but not limited to):

- Pressure in H2-storage;
- Temperature in H2-storage;
- Amount of H2 (kg) in storage;
- Power consumption;
- System efficiency;
- Status of the installation.

3.5.2. Operation and availability of personnel

Although the installation operates automatically and autonomously, it is assumed that an operator is present in the close vicinity of the installation, who can intervene in case of calamities.

3.6. HSE

3.6.1. Toxicity and exposure limits

Nitrogen is used in the electrolyser for purging purposes. In case of a leak this results in a risk of suffocation. An oxygen detector is included in the installation, which gives an alarm when the oxygen level drops below a certain level.

3.6.2. Fire- and explosion safety

During the engineering phase, an ATEX analysis will be performed. Because hydrogen is used, it is expected that at least a certain amount of ventilation will be required. A separate calculation will be performed in order to determine this ventilation requirement. Due to the amount of flammable gas stored, zoning could be required for the storage facilities. As the exact amount is still to be determined, this will be determined in a later stage.

3.6.3. Emissions and waste

It is expected that there will be some drains in the water treatment systems through which concentrate is drained.

At several points within the installation, safety relief valves will be placed to vent hydrogen in case of emergencies. These safety vents will be placed at a sufficient height above field level to ensure that the gasses can escape safely. In general use, no gas will be vented here. All vents will be adequately earthed in order to prevent built-up of static energy, such that no sparks can emerge and cause ignition.

In case oxygen is not used, it will be vented to the atmosphere, though this is not part of the scope of MTSA. Oxygen should be released at a safe distance from the hydrogen safety vent. In the lay-out drawing, vent positions will be marked and it will be ensured that they are located at a safe distance from each other. Attention will also be paid to the location of the oxygen vent to ensure that it is far enough from oxygen-sensitive surfaces in order to prevent effects such as corrosion.

3.6.4. Local legislation and rules – HSE

At this point, local legislation and rules that are to be complied to are not yet known as a final location has not yet been determined. It is assumed that when a location is selected and special rules apply, MTSA will be notified about this by W+B during a later stage in order to comply with this. All national legislation will be fulfilled.

3.6.5. Risk analysis and safety study

MTSA will perform the necessary safety studies such as a RIE and HAZOP. The results of these studies will be processed in the final basic design.

3.6.6. Certification and documentation

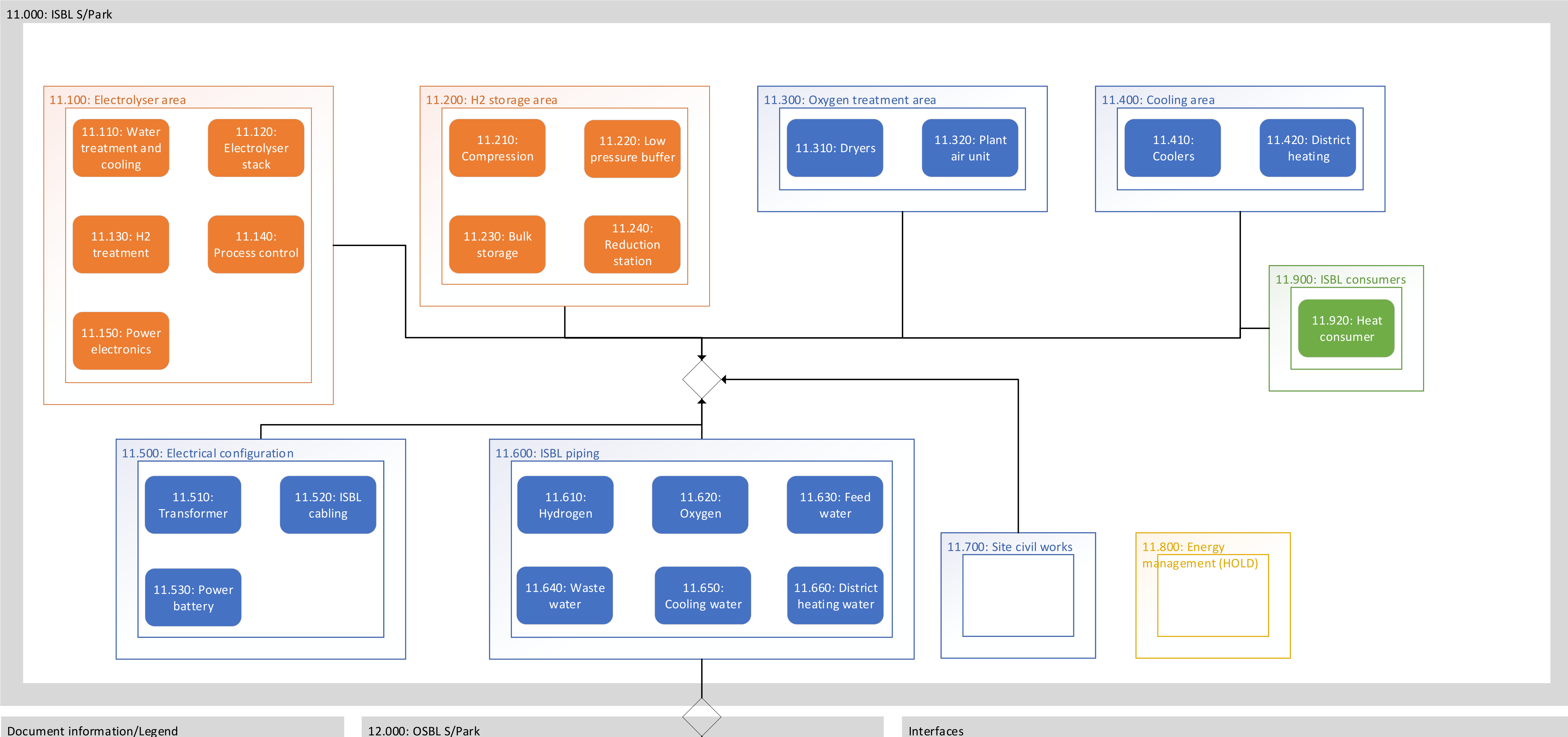
The following directives are considered:

- 2006/42/EG Machine Directive
- 2014/35/EU Low voltage directive
- 2014/68/EU PED directive
- 2014/30/EU EMC directive
- 2014/34/EU ATEX directive

These will be verified using norms and standards, which are related to the mentioned directives.

Appendix I

Work Breakdown Structure (by W+B)

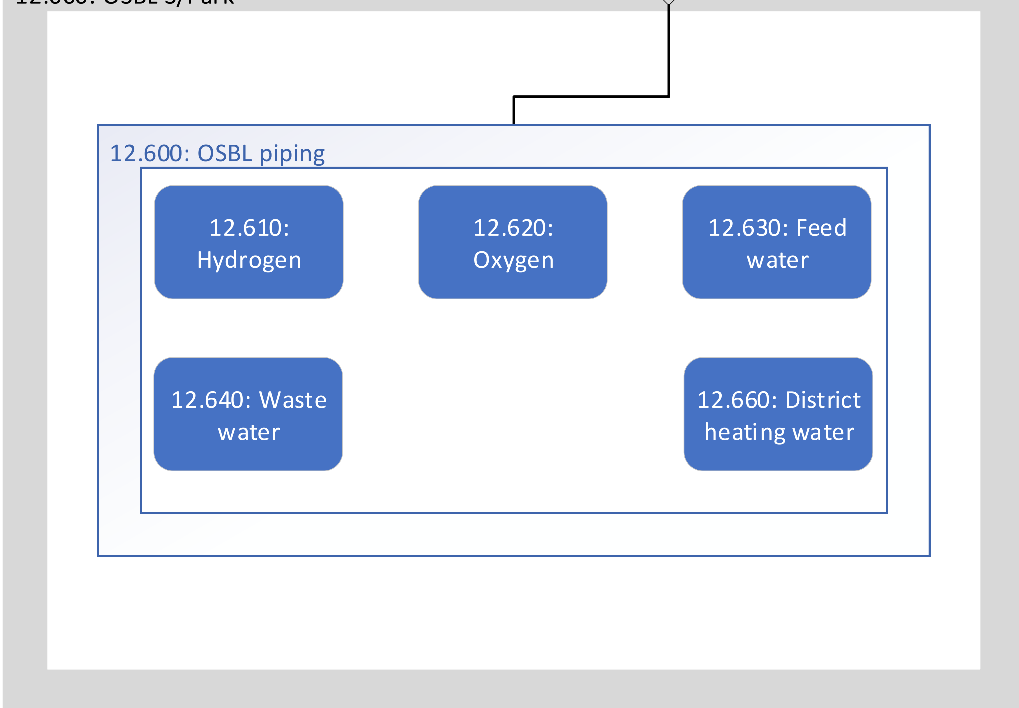


Document information/Legend

Title: Work breakdown structure S/Park
Version: 2
Date: 8-6-2021

W+B
MTSA
Van Dorp
Saxion/ Hanzenet

Interface

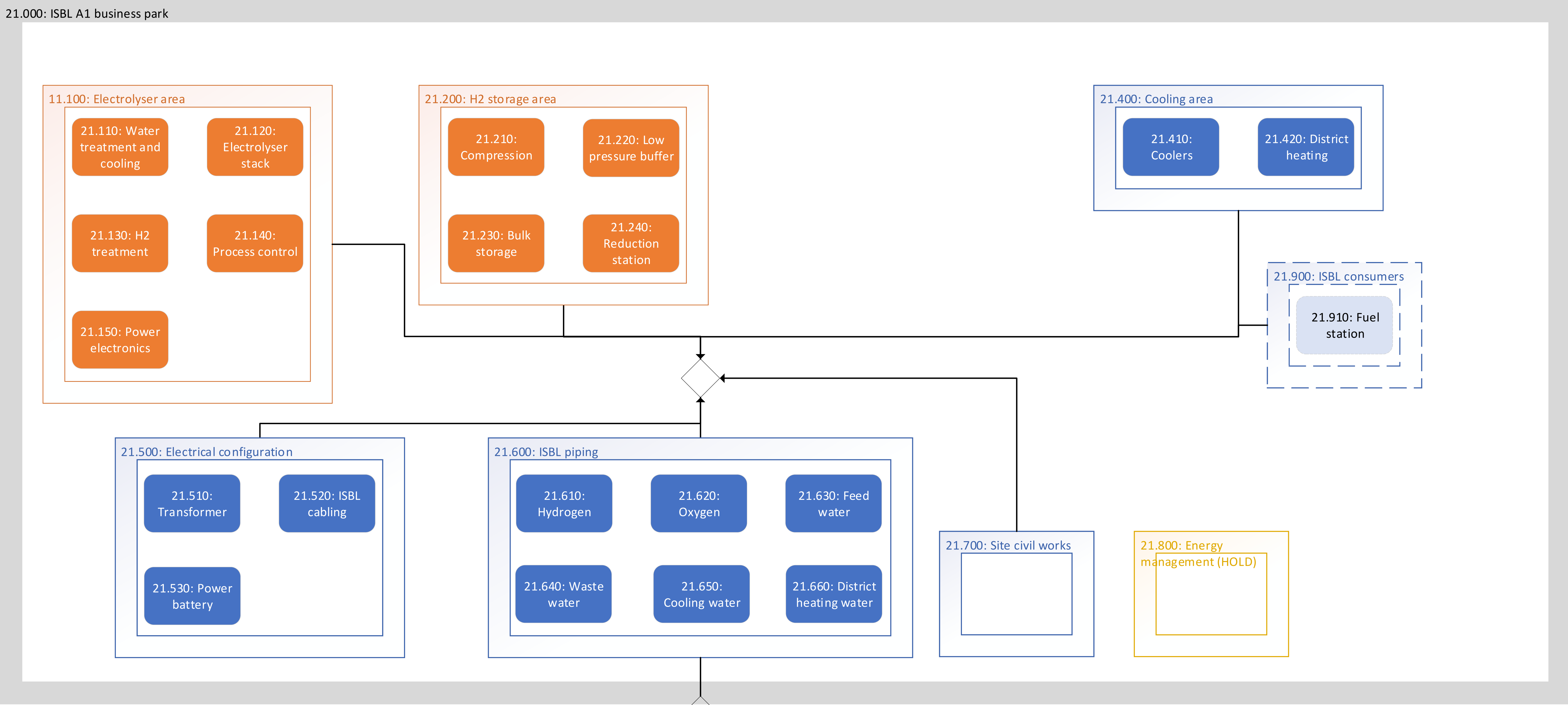


Interfaces

1. Power supply to:
   a. Electrolyser area
   b. H2 storage area
   c. Oxygen treatment area
   d. Cooling area
   e. Heat consumer

2. Piping:
   a.Hydrogen between electrolyser area, storage area and OSBL piping
   b. Oxygen from electrolyser area, to treatment area and to OSBL piping
   c. Feed water from OSBL piping to electrolyser area
   d. Waste water from electrolyser and oxygen treatment area to OSBL piping
   e. Cooling water from electrolyser area and storage area (HOLD) to cooling area
   f. District heating water from cooling area to heat consumer and OSBL piping (HOLD)

3. Site civil works requires input from all other work packages

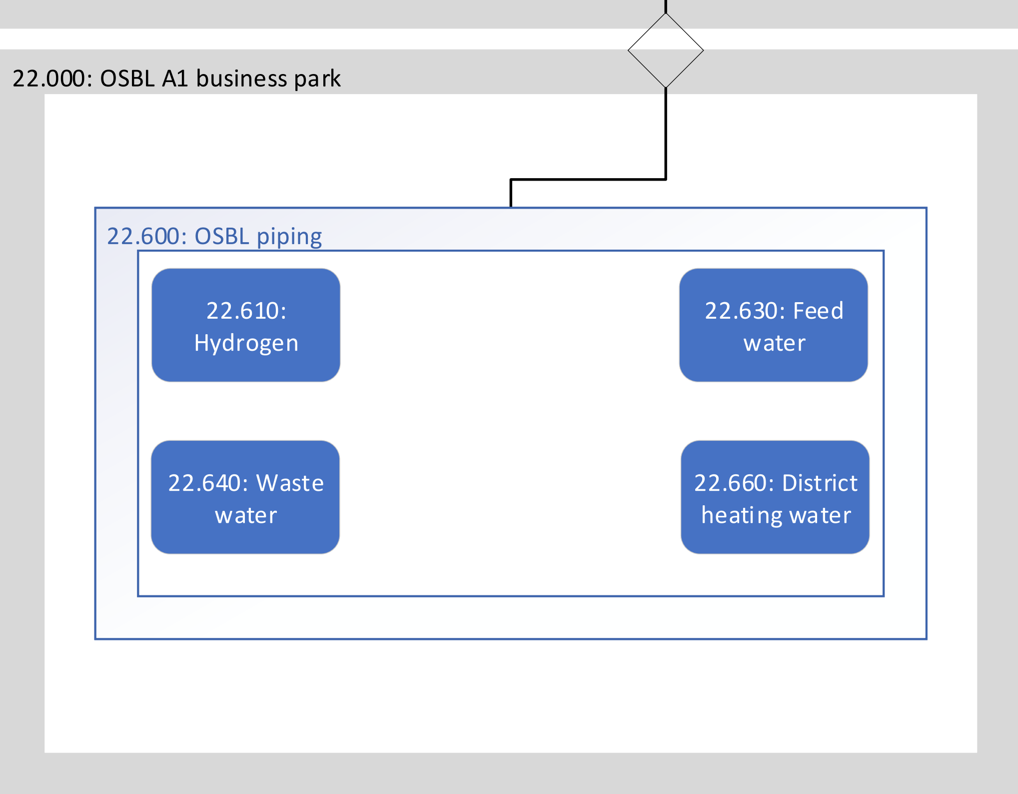


Document information/Legend

Title: Work breakdown structure A1 business park
Version: 2
Date: 18-6-2021

W+B
MTSA
Van Dorp
Saxion/ Hanzenet

Interface



Interfaces

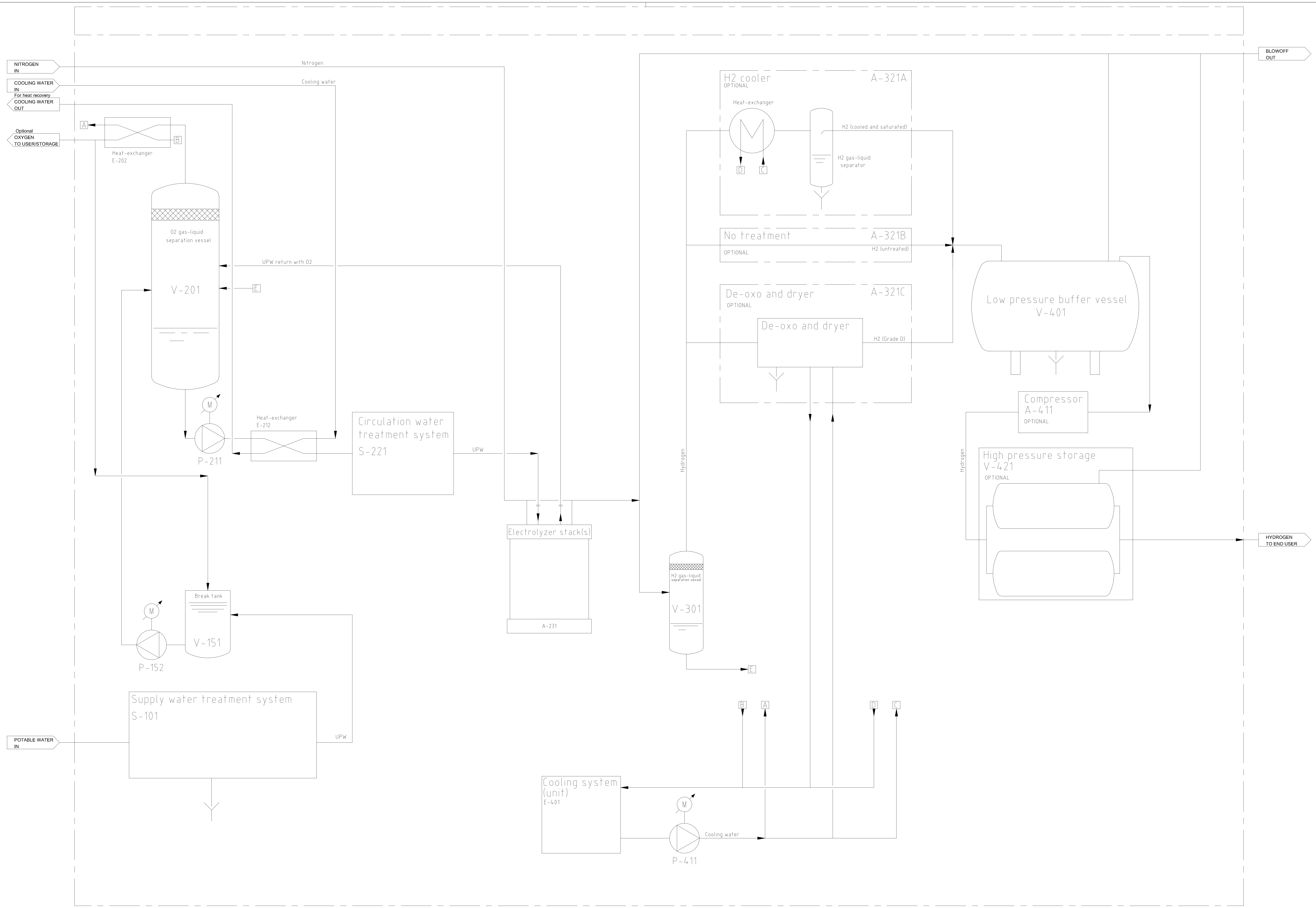
1. Power supply to:
   a. Electrolyser area
   b. H2 storage area
   d. Cooling area
   f. Fuel station

2. Piping:
   a. Hydrogen between electrolyser area, storage area, fuel station and OSBL piping
   c. Feed water from OSBL piping to electrolyser area
   d. Waste water from electrolyser and oxygen treatment area to OSBL piping
   e. Cooling water from electrolyser area and storage area (HOLD) to cooling area
   f. District heating water from cooling area to OSBL piping (HOLD)

3. Site civil works requires input from all other work packages

Appendix II

Schematic overview of the process (by MTSA)



	Date	Initials
Drawn	02-04-2021	TK
Checked		
Approved		

MTSA TECHNOPOWER

Electrolyser, compressor and storage

Schematic diagram

Rev.	Description	Date	By
1	Minor changes	28-04-21	TK
0	First issue	02-04-21	TK

Size	Drawing number	Sheet	Rev.
A2	1900601R-007	1	1

VIII

APPENDIX: SYSTEM SPECIFICATIONS 1 AND 2 MW

Overview Elektrolyser performance

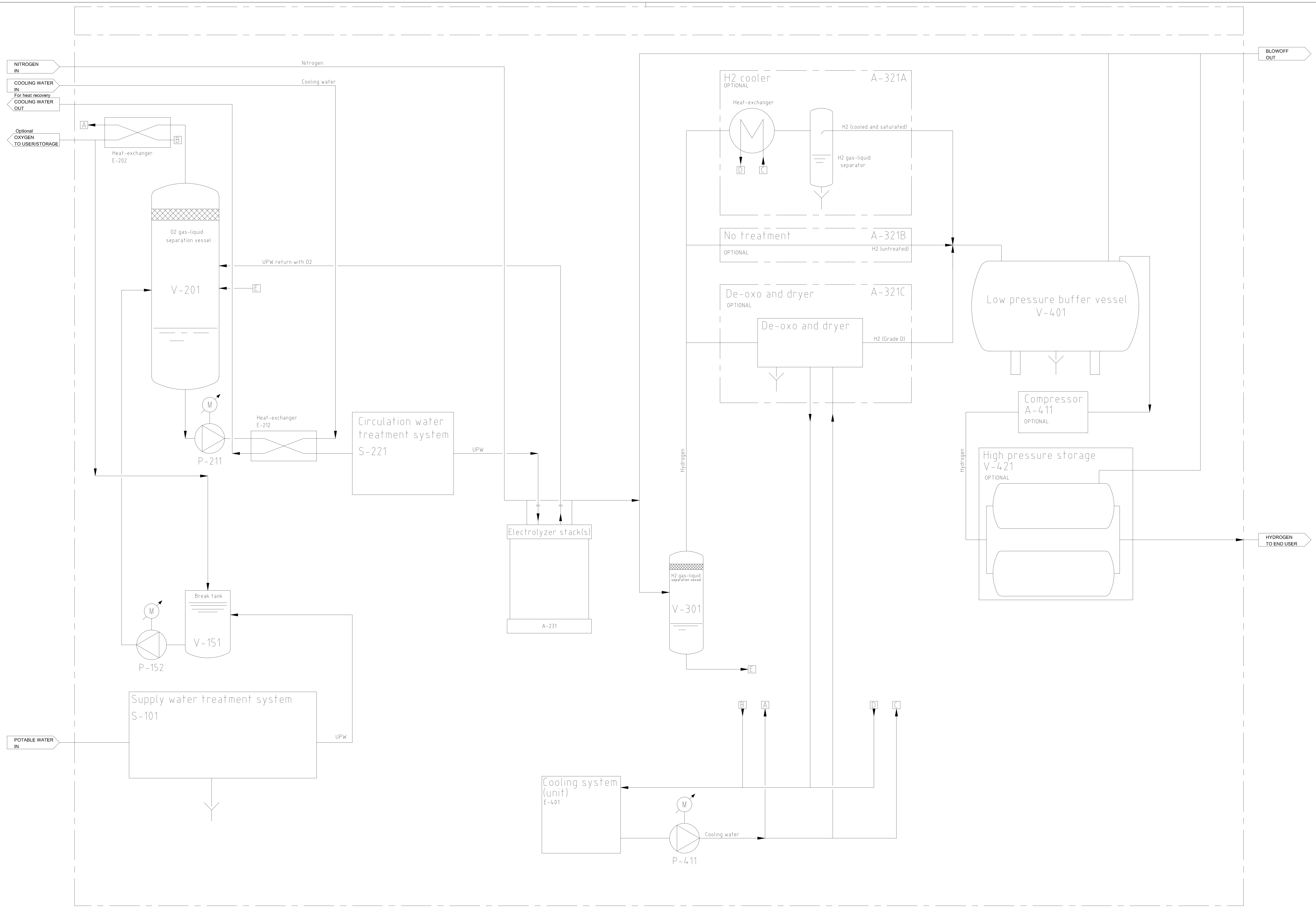
Property	Value	Unit	Limit min	Limit max	OK?
Electrical data					
Electrical power consumed	943,31	kW			
Voltage (total)	251,55	V			
Voltage (cell)	1,95	V	*1,5*	*2,4*	**YES**
Current	3750	A	*375*	*3750*	**YES**
Power consumption (cell)	7,31	kW/cell			
Percentage of max. consumption	100%				
Phase of life	BOL				
Production					
Mass flow H2	17,802	kg/h			
Water consumption	232,27	kg/h			
Temperature H2 (in K)	290,70	K			
Temperature H2 (in C)	17,55	°C			
Pressure H2 (to low pressure buffer)	37,00	bar(g)			
In case deoxo and drying is used:					
Water content in H2	5	µmol/mol	*0*	*5*	**YES**
Stack					
Inlet temperature	333,15	K	*278,15*	*338,15*	**YES**
Outlet temperature	337,42	K	*278,15*	*343,15*	**YES**
Temperature difference	4,27	K	*0*	*5,5*	**YES**
Inlet pressure	7,20	bar(g)	*0*	*11*	**YES**
Outlet pressure return	4,20	bar(g)	*0*	*11*	**YES**
Outlet pressure H2	40,00	bar(g)	*0*	*40*	**YES**
Pressure difference over membrane	32,80	bar	*0,1*	*40*	**YES**
Performance					
Energy consumption per kg H2	52,99	kWh/kg H2			
Water consumption per kg H2	13,06	L/kg			

Overview Elektrolyser performance

Property	Value	Unit	Limit min	Limit max	OK?
Electrical data					
Electrical power consumed	2128,50	kW			
Voltage (total)	283,80	V			
Voltage (cell)	2,2	V	*1,5*	*2,4*	**YES**
Current	3750	A	*375*	*3750*	**YES**
Power consumption (cell)	8,25	kW/cell			
Percentage of max. consumption	100%				
Phase of life	EOL				
Production					
Mass flow H2	35,603	kg/h			
Water consumption	464,78	kg/h			
Temperature H2 (in K)	290,70	K			
Temperature H2 (in C)	17,55	°C			
Pressure H2 (to low pressure buffer)	37,00	bar(g)			
In case deoxo and drying is used:					
Water content in H2	5	µmol/mol	*0*	*5*	**YES**
Stack					
Inlet temperature	333,15	K	*278,15*	*338,15*	**YES**
Outlet temperature	339,25	K	*278,15*	*343,15*	**YES**
Temperature difference	6,10	K	*0*	*5,5*	**NO**
Inlet pressure	9,90	bar(g)	*0*	*11*	**YES**
Outlet pressure return	4,20	bar(g)	*0*	*11*	**YES**
Outlet pressure H2	40,00	bar(g)	*0*	*40*	**YES**
Pressure difference over membrane	30,10	bar	*0,1*	*40*	**YES**
Performance					
Energy consumption per kg H2	59,78	kWh/kg H2			
Water consumption per kg H2	13,07	L/kg			

IX

APPENDIX: PFD 1 AND 2 MW



	Date	Initials
Drawn	02-04-2021	TK
Checked		
Approved		

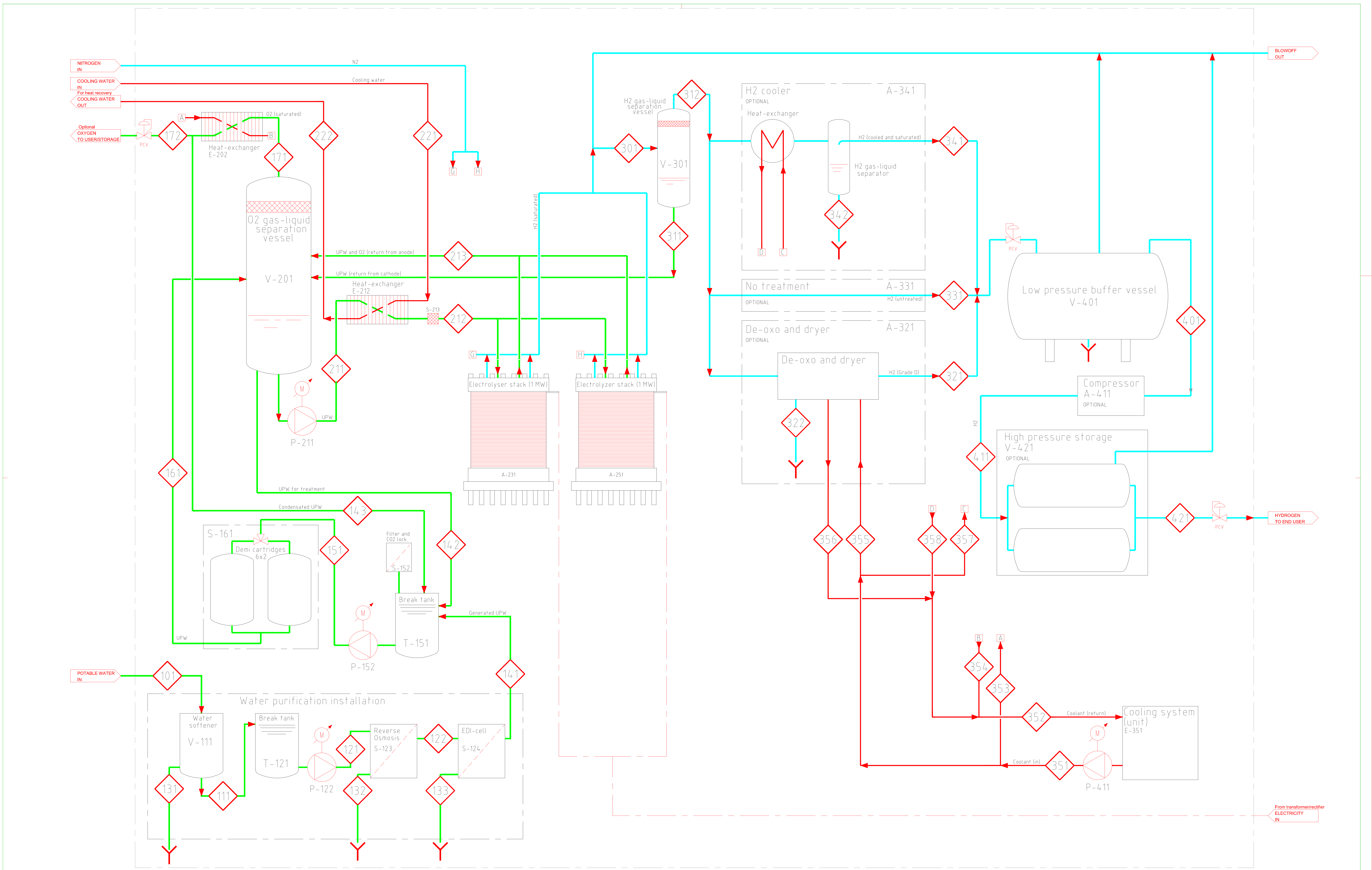
MTSA TECHNOPOWER

Electrolyser, compressor and storage

Schematic diagram

Rev.	Description	Date	By
1	Minor changes	28-04-21	TK
0	First issue	02-04-21	TK

Size	Drawing number	Sheet	Rev.
A2	1900601R-007	1	1



	Date	Initials
Drawn	17-03-2021	TK
Checked	09-09-2021	WF
Approved		

MTSA TECHNOPOWER

Electrolyser, compressor and storage

PFD

Rev	Description	Date	By
1	Overhaul	26-08-21	TK
0	First issue	17-03-21	TK

Size	Drawing number	Sheet	Rev
A2	1900601R-009	1	1

X

APPENDIX: MASS BALANCE 1 AND 2 MW

Document	Material balance	Project	GROHW	Revision	0
Document number	1900601R-010	Customer	MTSA	By	T.K.
Project nr.	1900601R	Location	Deventer, NL	Date	25-8-2021
Ordernr.				Checked	

Situation: 1MW, 1 stack, BOL

Water treatment, UPW circulation and O2-production

Stream	Tap water inlet	Softened water	Waste H2O	Pressurized water	From RO	Waste water	From EDI	Waste watei	To be polished	From O2-cooling
Description :	Before V-111	Before T-121	After V-111	After P-122	After S-123	From S-123	After S-124	From S-124	From V-201	From E-202
Stream number :	**101**	**111**	**131**	**121**	**122**	**132**	**141**	**133**	**142**	**143**
Temperature [ºC]	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00
Temperature [ºK]	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15
Pressure [bar(g)]	0,50	0,00	0,00	3,00	1,50	1,50	0,00	0,00	0,00	0,00
MassFlow [kg/h]	232,27	222,98	9,29	222,98	178,39	44,60	160,55	17,84	11773,59	3,37
MassFlow [kg/s]	0,065	0,062	0,003	0,062	0,050	0,012	0,045	0,005	3,270	0,001
Density [kg/m³]	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28
Flow [m³/h]	0,23	0,22	0,009	0,22	0,18	0,045	0,16	0,018	11,78	0,0034
MassFlow H2O [kg/h]	232,27	222,98	9,29	222,98	178,39	44,60	160,55	17,84	11773,59	3,37
MassFlow H2 [kg/h]	0	0	0	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	0	0	0	0	0	0	0	0
Density H2O [kg/m³]	999,126	999,103	999,103	999,243	999,173	999,173	999,103	999,103	999,103	999,103
Density H2 [kg/m³]	0,13	0,09	0,09	0,34	0,21	0,21	0,09	0,09	0,09	0,09
Density O2 [kg/m³]	2,02	1,35	1,35	5,38	3,36	3,36	1,35	1,35	1,35	1,35
Conductivity [µS/cm]	500	500	500	500	8	*High*	0,055	*High*	0,055	0,055
State	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Min. piping D [mm]	7,4	7,3	1,5	7,3	6,5	3,2	6,2	2,1	52,7	0,9

Water treatment, UPW circulation and O2-production

Stream	Pressurized UPW	UPW to V-201	O2 with UPW	O2 outlet	UPW under press.	UPW to Stack	Return UPW w/O2
Description :	From P-152	From S-161	From V-201/to E-202	From E-202	After P-211	After S-213	After A-231 (anode)
Stream number :	**151**	**161**	**171**	**172**	**211**	**212**	**213**
Temperature [ºC]	63,59	63,59	64,27	25,00	64,27	60,00	64,27
Temperature [ºK]	336,74	336,74	337,42	298,15	337,42	333,15	337,42
Pressure [bar(g)]	4,70	4,20	4,20	4,00	7,60	7,20	4,20
MassFlow [kg/h]	11937,51	11937,51	145,17	141,80	57092,79	57092,79	55960,36
MassFlow [kg/s]	3,32	3,32	0,040	0,039	15,86	15,86	15,54
Density [kg/m³]	0,27	0,27	0,0017	0,0018	0,27	0,27	0,19
Flow [m³/h]	12,16	12,16	23,73	21,76	58,18	58,05	80,62
MassFlow H2O [kg/h]	11937,51	11937,51	3,88	0,51	57092,79	57092,79	55819,07
MassFlow H2 [kg/h]	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	141,29	141,29	0	0	141,29
Density H2O [kg/m³]	981,52	981,49	981,13	997,23	981,28	983,51	981,13
Density H2 [kg/m³]	0,41	0,37	0,37	0,41	0,62	0,60	0,37
Density O2 [kg/m³]	6,54	5,97	5,96	6,49	9,85	9,51	5,96
Conductivity [µS/cm]	0,055	< 0,055	*N/A*	*N/A*	< 0,055	< 0,055	< 0,055
State	Liquid	Liquid	Gas	Gas	Liquid	Liquid	Liquid
Min. piping D [mm]	53,55	53,55	23,65	22,65	117,13	116,99	137,87

H2 production and treatment

Stream	Sat., wet, hot H2	Return UPW	Saturated, hot H2	Treated H2 (deoxo)	Waste H2O	Untreated H2	Treated H2 (cooled)	Waste H2O
Description :	After A-231/251 (ca)	After V-301	After V-301	After A-321	From A-321	After A-331	After A-341	From A-341
Stream number :	**301**	**311**	**312**	**321**	**322**	**331**	**341**	**342**
Temperature [ºC]	64,27	64,27	64,27	17,55	17,55	64,27	15,00	17,55
Temperature [ºK]	337,42	337,42	337,42	290,70	290,70	337,42	288,15	290,70
Pressure [bar(g)]	40,00	40,00	40,00	38,30	38,30	40,00	39,80	38,30
MassFlow [kg/h]	1132,43	1113,68	18,75	17,80	0,95	18,75	17,87	0,88
MassFlow [kg/s]	0,31	0,31	0,005	0,005	0,00026	0,005	0,005	0,00024
Density [kg/m³]	0,04	0,27	0,00	0,00	0,28	0,00	0,00	0,27
Flow [m³/h]	7,31	1,13	6,18	5,56	0,0009	6,18	5,31	0,0009
MassFlow H2O [kg/h]	1114,62	1113,68	0,95	0,0008	0,95	0,95	0,07	0,88
MassFlow H2 [kg/h]	17,80	0	17,80	17,80	0	17,80	17,80	0,00
MassFlow O2 [kg/h]	0,0031	0	0,0031	0	0	0,0031	0,0031	0
Density H2O [kg/m³]	982,70	982,70	982,70	1000,44	1000,44	982,70	1000,95	1000,44
Density H2 [kg/m³]	2,88	2,88	2,88	3,20	3,20	2,88	3,35	3,20
Density O2 [kg/m³]	47,29	47,29	47,29	53,46	53,46	47,29	56,11	53,46
Conductivity [µS/cm]	N/A	< 0,055	N/A	N/A	N/A	N/A	N/A	N/A
State	Gas	Liquid	Gas	Gas	Liquid	Gas	Liquid	Gas
Min. piping D [mm]	13,13	16,35	12,07	11,45	0,47	12,07	35,39	0,15

Heating and cooling flows

Stream	Coolant in, UPW	Coolant out, UPW	Main cool line	Main cool return	To O2 cooler	From O2 cooler	To deoxo/dryer	ım deoxo/dr	To H2 cooler	From H2 cooler
Description :	To E-212	From E-212	From E-351	To E-202	To E-202	From E-301	To A-321	From A-321	To A-341	From A-341
Stream number :	**221**	**222**	**351**	**352**	**353**	**354**	**355**	**356**	**357**	**358**
Temperature [ºC]	55,00	60,00	10,00	25,00	10,00	25,00	10,00	25,00	10,00	25,00
Temperature [ºK]	328,15	333,15	283,15	298,15	283,15	298,15	283,15	298,15	283,15	298,15
Pressure [bar(g)]	6,00	5,60	6,00	4,00	6,00	4,00	6,00	4,00	6,00	4,00
% of glycol in water	0%	0%	10%	10%	10%	10%	10%	10%	10%	10%
MassFlow [kg/h]	48754,47	48754,47	3310,16	3310,16	272,61	272,61	3037,55	3037,55	304,95	304,95
MassFlow [kg/s]	13,54	13,54	0,92	0,92	0,08	0,08	0,84	0,84	0,08	0,08

Document	Material balance	Project	GROHW	Revision	0
Document number	1900601R-010	Customer	MTSA	By	T.K.
Project nr.	1900601R	Location	Deventer, NL	Date	25-8-2021
Ordernr.				Checked	

MTSA TECHNOPOWER

Situation:	2MW, 2 stacks, EOL

Water treatment, UPW circulation and O2-production

Stream	Tap water inlet	Softened water	Waste H2O	Pressurized water	From RO	Waste water	From EDI	Waste watei	To be polished	From O2-cooling
Description :	Before V-111	Before T-121	After V-111	After P-122	After S-123	From S-123	After S-124	From S-124	From V-201	From E-202
Stream number :	**101**	**111**	**131**	**121**	**122**	**132**	**141**	**133**	**142**	**143**
Temperature [ºC]	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00
Temperature [ºK]	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15
Pressure [bar(g)]	0,50	0,00	0,00	3,00	1,50	1,50	0,00	0,00	0,00	0,00
MassFlow [kg/h]	464,78	446,19	18,59	446,19	356,95	89,24	321,26	35,70	11761,64	7,44
MassFlow [kg/s]	0,129	0,124	0,005	0,124	0,099	0,025	0,089	0,010	3,267	0,002
Density [kg/m³]	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28
Flow [m³/h]	0,47	0,45	0,019	0,45	0,36	0,089	0,32	0,036	11,77	0,0074
MassFlow H2O [kg/h]	464,78	446,19	18,59	446,19	356,95	89,24	321,26	35,70	11761,64	7,44
MassFlow H2 [kg/h]	0	0	0	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	0	0	0	0	0	0	0	0
Density H2O [kg/m³]	999,126	999,103	999,103	999,243	999,173	999,173	999,103	999,103	999,103	999,103
Density H2 [kg/m³]	0,13	0,09	0,09	0,34	0,21	0,21	0,09	0,09	0,09	0,09
Density O2 [kg/m³]	2,02	1,35	1,35	5,38	3,36	3,36	1,35	1,35	1,35	1,35
Conductivity [µS/cm]	500	500	500	500	8	*High*	0,055	*High*	0,055	0,055
State	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Min. piping D [mm]	10,5	10,3	2,1	10,3	9,2	4,6	8,7	2,9	52,7	1,3

Water treatment, UPW circulation and O2-production

Stream	Pressurized UPW	UPW to V-201	O2 with UPW	O2 outlet	UPW under press.	UPW to Stack	Return UPW w/O2
Description :	From P-152	From S-161	From V-201/to E-202	From E-202	After P-211	After S-213	After A-231 (anode)
Stream number :	**151**	**161**	**171**	**172**	**211**	**212**	**213**
Temperature [ºC]	64,71	64,71	66,10	25,00	66,10	60,00	66,10
Temperature [ºK]	337,86	337,86	339,25	298,15	339,25	333,15	339,25
Pressure [bar(g)]	4,70	4,20	4,20	4,00	10,30	9,90	4,20
MassFlow [kg/h]	12090,34	12090,34	291,03	283,60	114199,26	114199,26	111934,25
MassFlow [kg/s]	3,36	3,36	0,081	0,079	31,72	31,72	31,09
Density [kg/m³]	0,27	0,27	0,0017	0,0018	0,27	0,27	0,19
Flow [m³/h]	12,33	12,33	47,72	43,53	116,48	116,10	161,62
MassFlow H2O [kg/h]	12090,34	12090,34	8,45	1,01	114199,26	114199,26	111651,67
MassFlow H2 [kg/h]	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	282,58	282,58	0	0	282,58
Density H2O [kg/m³]	980,91	980,89	980,14	997,23	980,40	983,63	980,14
Density H2 [kg/m³]	0,41	0,37	0,37	0,41	0,80	0,79	0,37
Density O2 [kg/m³]	6,52	5,95	5,92	6,49	12,88	12,65	5,92
Conductivity [µS/cm]	0,055	< 0,055	*N/A*	*N/A*	< 0,055	< 0,055	< 0,055
State	Liquid	Liquid	Gas	Gas	Liquid	Liquid	Liquid
Min. piping D [mm]	53,91	53,91	33,54	32,04	165,72	165,45	195,21

H2 production and treatment

Stream	Sat., wet, hot H2	Return UPW	Saturated, hot H2	Treated H2 (deoxo)	Waste H2O	Untreated H2	Treated H2 (cooled)	Waste H2O
Description :	After A-231/251 (ca)	After V-301	After V-301	After A-321	From A-321	After A-331	After A-341	From A-341
Stream number :	**301**	**311**	**312**	**321**	**322**	**331**	**341**	**342**
Temperature [ºC]	66,10	66,10	66,10	17,55	17,55	66,10	15,00	17,55
Temperature [ºK]	339,25	339,25	339,25	290,70	290,70	339,25	288,15	290,70
Pressure [bar(g)]	40,00	40,00	40,00	38,30	38,30	40,00	39,80	38,30
MassFlow [kg/h]	2265,01	2227,35	37,66	35,60	2,06	37,66	35,74	1,92
MassFlow [kg/s]	0,63	0,62	0,010	0,010	0,00057	0,010	0,010	0,00053
Density [kg/m³]	0,04	0,27	0,00	0,00	0,28	0,00	0,00	0,27
Flow [m³/h]	14,69	2,27	12,42	11,11	0,0021	12,42	10,62	0,0020
MassFlow H2O [kg/h]	2229,40	2227,35	2,05	0,0016	2,06	2,05	0,13	1,92
MassFlow H2 [kg/h]	35,60	0	35,60	35,60	0	35,60	35,60	0,00
MassFlow O2 [kg/h]	0,0062	0	0,0062	0	0	0,0062	0,0062	0
Density H2O [kg/m³]	981,70	981,70	981,70	1000,44	1000,44	981,70	1000,95	1000,44
Density H2 [kg/m³]	2,87	2,87	2,87	3,20	3,20	2,87	3,35	3,20
Density O2 [kg/m³]	47,02	47,02	47,02	53,46	53,46	47,02	56,11	53,46
Conductivity [µS/cm]	N/A	< 0,055	N/A	N/A	N/A	N/A	N/A	N/A
State	Gas	Liquid	Gas	Gas	Liquid	Gas	Liquid	Gas
Min. piping D [mm]	18,61	23,13	17,11	16,19	0,70	17,11	50,05	0,21

Heating and cooling flows

Stream	Coolant in, UPW	Coolant out, UPW	Main cool line	Main cool return	To O2 cooler	From O2 cooler	To deoxo/dryer	m deoxo/dr	To H2 cooler	From H2 cooler
Description :	To E-212	From E-212	From E-351	To E-202	To E-202	From E-301	To A-321	From A-321	To A-341	From A-341
Stream number :	**221**	**222**	**351**	**352**	**353**	**354**	**355**	**356**	**357**	**358**
Temperature [ºC]	55,00	60,00	10,00	25,00	10,00	25,00	10,00	25,00	10,00	25,00
Temperature [ºK]	328,15	333,15	283,15	298,15	283,15	298,15	283,15	298,15	283,15	298,15
Pressure [bar(g)]	6,00	5,60	6,00	4,00	6,00	4,00	6,00	4,00	6,00	4,00
% of glycol in water	0%	0%	10%	10%	10%	10%	10%	10%	10%	10%
MassFlow [kg/h]	139377,76	139377,76	3626,69	3626,69	589,14	589,14	3037,55	3037,55	637,35	637,35
MassFlow [kg/s]	38,72	38,72	1,01	1,01	0,16	0,16	0,84	0,84	0,18	0,18

XI

APPENDIX: BASIS OF DESIGN (BOD)

GROHW

Basis of Design - Electrolyzer A1-Business Park

Provincie Overijssel

28 January 2022

Project	GROHW
Client	Provincie Overijssel
Document	Basis of Design - Electrolyzer A1-Business Park
Status	REV-A
Date	28 January 2022
Reference	RAP-04-WB-119017-4-REV-A
Project code	119017
Project Leader	Fenna van de Watering
Project Director	Raphaël van der Velde
Author(s)	Lotte Berkelaar
Checked by	Samuel Schöffer, Isabelle Vlasman
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1

PREFACE

1.1 Context of GROHW

A collective of 11 local companies and institutions are joining forces to accelerate the energy transition by collaborating on project GROHW. GROHW stands for **GR**een **O**xygen, **H**ydrogen and **W**asteheat. The participating parties are forerunners in their own sector and share their knowledge and experience in this project. 'Together we are building the energy transition with green hydrogen as the most important building block. '

Within this consortium we develop the most optimal system for the entire hydrogen chain on a local scale: from production to utilization. The central question we are answering is 'How can we use green hydrogen production to prevent overloading of the grid, so that we remain sustainable in the short term on a local and affordable level? Beside hydrogen production, we are also looking at the utilization of oxygen, heat and how we can positively support the local grid. In addition, we are developing a digital trading platform, where we cleverly manage and offset energy flows.

The local green hydrogen hub thus serves several purposes:
- Producing green hydrogen on a local scale
- Utilizing local renewable energy directly to alleviate grid overloading
- Utilizing the co-products of electrolysis: oxygen and heat
- The development of a digital trading platform

The city of Deventer is currently the pilot location, but this is only the beginning of GROHW. The ultimate goal is to create a blueprint that can be used in similar areas around the world. This means that we will try to learn the lessons in the pilot location, and evaluate and translate our findings into a standard methodology: the blueprint.

1.2 Hydrogen station Deventer

The province of Overijssel has set the goal to have 20 % of their energy renewable and to reduce energy consumption by 6 %. The municipality of Deventer wants to be energy-neutral by 2030 according to the 'Energieplan Deventer' (okt. 2020). Contrarily, network operator Enexis states that the electricity network as it is today is overloaded in terms of capacity and stability level. Due to this, there is no possibility at many places to provide new connections to realize sustainable energy production. This creates a demand for solutions to reach the set goals.

The solution to avoid overloading of the energy grid while connecting more renewable energy sources to it is a smart, local energy storage in an energy carrier such as hydrogen. The GROHW-collaboration, of which Witteveen+Bos is part, intends to place a new hydrogen hub alongside the A1 in Deventer with a capacity of 2 MW. This report compromises the BOD for part 1 of GROHW (also named GROHW-1), a project in which the possibilities of hydrogen stations are investigated. GROHW-1 has the goal to produce green hydrogen. The GROHW-1-collaboration consists of Witteveen+Bos, Saxion Hogeschool, Van Dorp, MTSA Technopower, Rabobank, VOS, Hanzenet, AsfaltNu, HAN University of Applied Sciences and Brandeniers.

In this report, the Basis of Design is composed as starting point for the design of the MW-scale hydrogen station in Deventer (GROHW-1). The scope is defined (chapter 2) and the functional requirements (chapter 3) are described.

2

SCOPE DEFINITION

2.1 Service scope

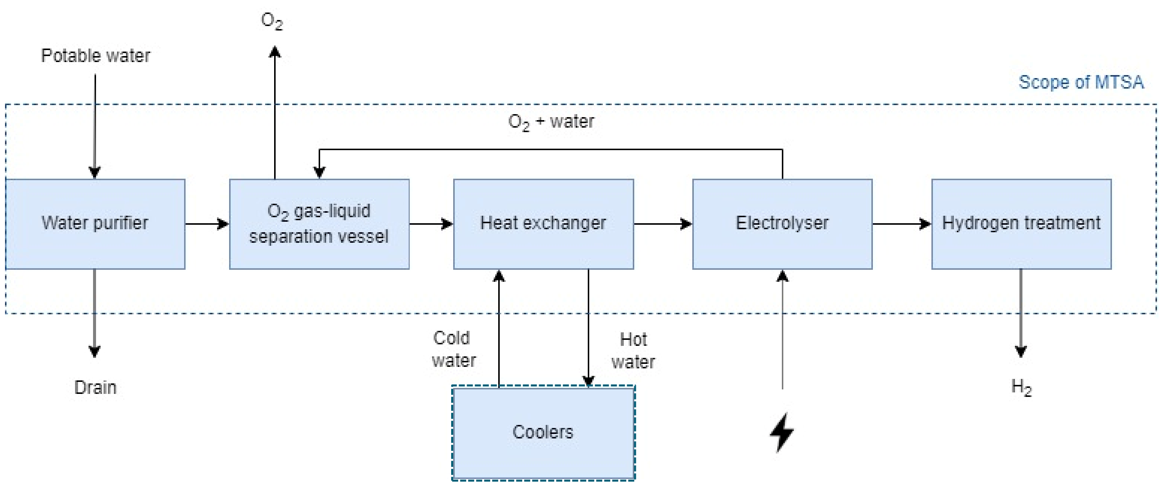
The hydrogen station is planned to be located at the A1 Business Park in Deventer, although this is not confirmed yet. For this reason, the BOD is made independently of the location, so that it functions as a basis not only for the currently selected A1 business park location, but for other hydrogen electrolyzer projects in the future as well. The green hydrogen in this project is produced by converting ultra-pure water (UPW, produced on-site) electrochemically into hydrogen and oxygen. These hydrogen and oxygen streams are then treated to reach desired purity, pressure and temperature before being sold to other parties.

2.2 Technical scope

The electrolyzer's main goal is to use the energy surplus at peak hours. It consists of two 1-MW electrolyzers, so its nominal power is 2 MW. The electricity is supplied by the grid. The systems runs 5000 full load hours annually which corresponds to the requirements of the subsidy of SDE++ and falls in the main category 'CO2-arme productie' (CO2 lean production) and the subcategory 'Waterstof door elektrolyse' (Hydrogen through Electrolysis).

Figure below shows the process design blocks. The PFD with corresponding mass balance can be found in Appendix I. This chapter describes the scope of Witteveen+Bos. For more information on the scope of MTSA, 'Starting points MTSA WP3' (1900601R-008, Rev 2, 27-05-2021) can be read. This report takes multiple locations and electrolyzer capacities into account, but the 'A1 location' and '2 MW electrolyzer' are the guidelines used for this BOD, as well as the route on Appendix I via area A-321.

Figure 2.1 Process design blocks



2.3 Design scope

In this paragraph the scopes of MTSA and W+B are defined. The electrolyzer station is divided in eight main components:

1 The electrolyzer
2 Hydrogen storage
3 Oxygen treatment
4 Cooling
5 Electrical configuration
6 ISBL piping
7 Utility
8 Civil works

The next chapter describes these main components, as well as the safety and regulations in further detail.

Appendix I shows the schematic diagram (PFD with mass balance) of the system.

Regarding the scope borders, Witteveen+Bos takes care of the connection to the hub within 1 meter of the MTSA installation, after which MTSA takes care of the connections of her own installation. A full schematic of the scope (Work Breakdown Structure[1]) is defined in the figure in Appendix II.

Liander is responsible for a medium voltage connection, including a cable to the site. Also present is Energy Management, which will be performed by Hanzenet. Hanzenet monitors the energy provision and demand and connects the two to obtain hydrogen optimization.

District heating is not included in this Basis of Design because there is no specific location available and thus no revenue model. However, it is a feasible option due to the large amount of heat produced at the electrolyzer.

[1] The WBS used in the MTSA document 'Starting points MTSA WP3' (1900601R-008, Rev 2, 27-05-2021) may in some cases differ from the WBS in Appendix II, in case of any discrepancies the WBS in Appendix II is prevailing.

3

PROCESS AND DESIGN CONDITIONS

In this chapter, the process and design conditions are described.

3.1 Electrolyzer area / MTSA scope

For the applied process and design conditions (including container) reference is made to the document of MTSA: 'Starting points MTSA WP3' (1900601R-008, Rev 2, 27-05-2021).

3.2 Hydrogen storage area

A low-pressure hydrogen storage is present as part of the electrolyzer. This hydrogen has the specifications as described in Table 3.1. A compressor is placed after the low-pressure hydrogen storage to increase the hydrogen pressure to 200 bar after which it is directly loaded in a tube trailer. Two connections for tube trailers are placed to secure filling and disconnecting of the tube trailers. Minimum capacity of tube trailers should be equal to the daily produced amount.

Table 3.1 Hydrogen output of low-pressure buffer vessel

Output	Quantity	Unit
Pressure	38	bar(g)
Temperature	20	ºC
Water concentration	<5	ppm
H2 Production at 2 MW	35,60	kg/hr
Yearly production	178	ton/year
Hydrogen Quality	Grade D (ISO 14687-2)	-

3.3 Oxygen treatment area

Oxygen comes out of the electrolyzer with the properties as defined in table below

Table 3.2 Oxygen output of electrolyzer

Output	Quantity	Unit
Pressure	4	bar(g)
Temperature	25	ºC
Water concentration	6300 (saturation)	ppm
Oxygen production at 2 MW	283	kg/hr
Yearly production	1415	ton/year

Oxygen is processed and sold. Based on a questionnaire returned from Westfalen and industry standards (Linde-gas), the oxygen needs to have the following properties:
- A purity of 99,5 % at least
- A maximum of 2 ppmv of water
- A pressure of 200 bar(g)

The oxygen from the electrolyzer is first dried in a dryer, then stored in a low-pressure storage vessel and finally compressed to industry standard levels. Oxygen is then stored at 200 bar(g) in 50L cylinders and can be picked up by an interested company.

3.4 Cooling area

The heat from the electrolyzers can be used in a district heating system. This can be done by flowing cooling water alongside the ultra-pure water to remove excess heat during the process. The cooling water is returned at a higher temperature. This water is cooled down and re-supplied to the system. This stream has the following properties at 2 MW:
- The mass of the stream is 140 t/h
- The temperature needs to be cooled from 60ºC to 55ºC

This corresponds to a cooling capacity of 815 kW. Due to the fact that the location is still unknown, the possibilities for using heat are not yet worked out.

3.5 Electrical configuration

A connection cable is placed between the connection point of Liander and the system. This connection is assumed to provide electricity for both the electrolysis itself as well as feeding the electrical equipment. For the 2 MW electrolyzer, 2,2 MVA is necessary for electrolysis, plus the electricity required for the electrical equipment in the installation. The installation should be connected to 10 kV. A transformer to 400 V is included in the electrolyzer package. It is assumed that the installations outside of the electrolyzer package can be connected to the low voltage side of this transformer.

3.6 ISBL piping

ISBL piping consists of the following components:
1 Hydrogen
2 Oxygen
3 Feed water
4 Waste water
5 Cooling water
6 District heating water

Components 1 to 4 are discussed below. Cooling water is out of scope and district heating water will not be designed and is therefore not further discussed.

Hydrogen and oxygen

ISBL piping of hydrogen is present between the connection between the hydrogen buffer vessel, compressor and the loading of the tube trailers. ISBL piping of oxygen is between the oxygen buffer, the oxygen treatment area and the loading of the oxygen tube trailers.

Feed water

Potable water with a flow rate of 456 kg/hr is provided to the system from the local drinking water grid.

Waste water

Drains are installed on the location to release waste water containing by-products. The by-product is concentrate from the water treatment installation. The exact composition is unknown but the impurities present in the water are the same for drinking water, but with a higher concentration. A connection between the system and the sewer system is provided.

3.7 Utility area

Instrument air

Instrument air or compressed air has to be present to operate the pneumatically operated valves.

Nitrogen

A nitrogen supply has to be supplied at the site to purge the system.

3.8 Site civil works

The oxygen treatment and the electrical equipment for the oxygen treatment are placed in a separate 40 ft container. This container needs to have the following specifications:
- Ventilation system
- Heating unit
- A separation wall between the electric equipment and oxygen treatment
- Two doors to access both areas
- Light
- Oxygen concentration measurer and alarm
- Isolation from external weather
- Sound reduction for compressors

Any specific (safety) requirements on e.g. ATEX are to be determined.

The total set-up consists of two 40 ft containers, one for the electrolyzer with the hydrogen treatment and one for the oxygen treatment. These containers must be placed on a stable underground, such as concrete (tiles) and if necessary earthwork has to be done, depending on the location. If the set-up is planned for a longer period, a building can be placed on top of the containers. A low-pressure hydrogen storage tank (outside), electrical cabling and pipelines transporting the hydrogen, oxygen and water are also present onsite, as well as a drain connected to the sewer system. The needed area is estimated at approx. 25x50 meter. A fence needs to be placed to surround the area, taking into consideration safety distances.

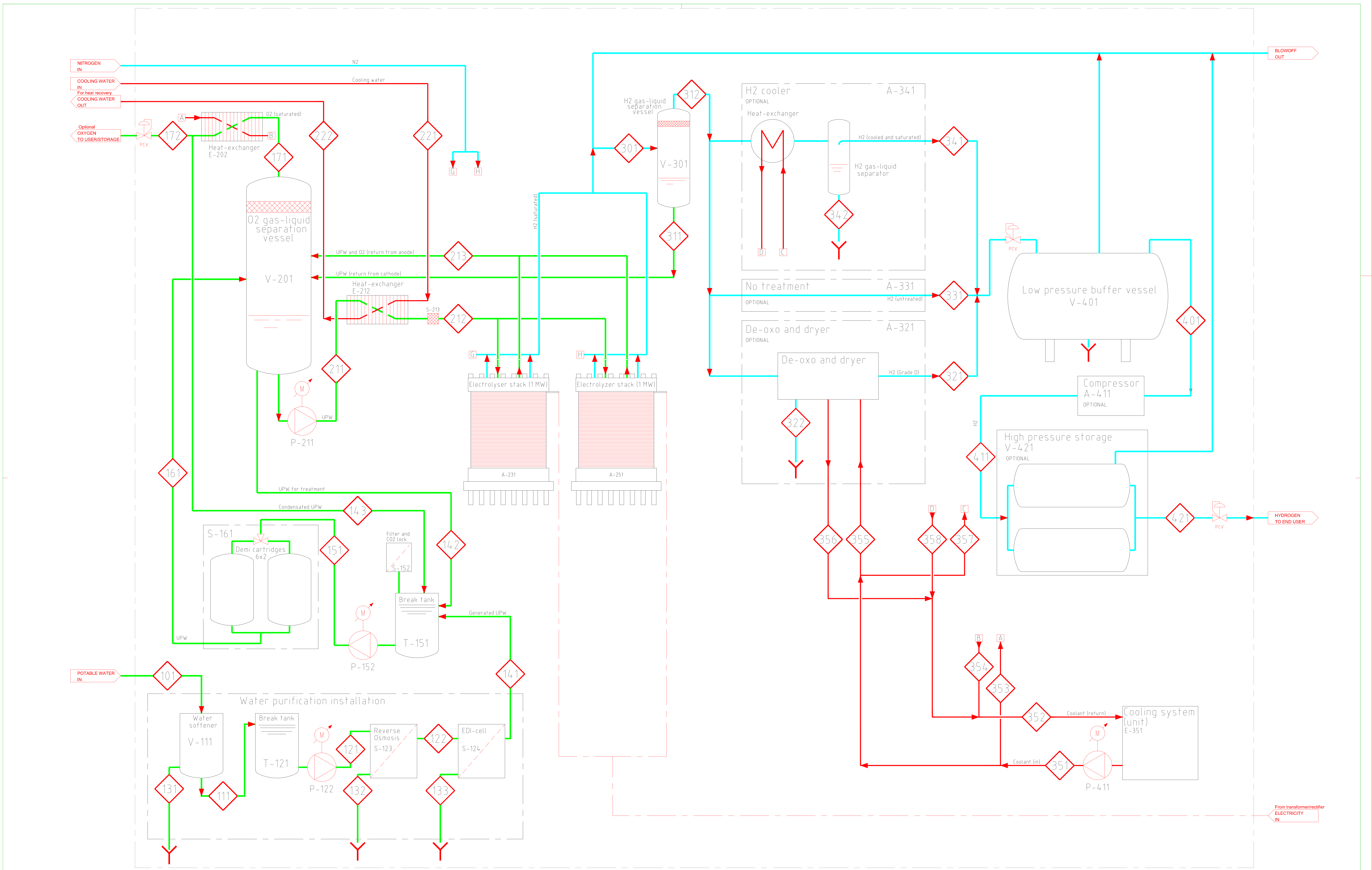
Next to that, parking spots need to be provided for the tube trailers to park when filling.

3.9 Safety and regulations

Safety and regulations can be found in the system design report (RAP-02-WB-119017-2-REV-A, 04-03-2021).

Appendices

APPENDIX: PFD & MASS BALANCE



	Date	Initials
Drawn	17-03-2021	TK
Checked	09-09-2021	WF
Approved		

Electrolyser, compressor and storage

PFD

MTSA TECHNOPOWER

Rev	Description	Date	By
1	Overhaul	26-08-21	TK
0	First issue	17-03-21	TK

Size	Drawing number	Sheet	Rev
A2	1900601R-009	1	1

Document	Material balance	Project	GROHW	Revision	0
Document number	1900601R-010	Customer	MTSA	By	T.K.
Project nr.	1900601R	Location	Deventer, NL	Date	25-8-2021
Ordernr.				Checked	

Situation:	2MW, 2 stacks, EOL

Water treatment, UPW circulation and O2-production

Stream	Tap water inlet	Softened water	Waste H2O	Pressurized water	From RO	Waste water	From EDI	Waste wate	To be polished	From O2-cooling
Description :	Before V-111	Before T-121	After V-111	After P-122	After S-123	From S-123	After S-124	From S-124	From V-201	From E-202
Stream number :	**101**	**111**	**131**	**121**	**122**	**132**	**141**	**133**	**142**	**143**
Temperature [ºC]	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00	15,00
Temperature [ºK]	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15	288,15
Pressure [bar(g)]	0,50	0,00	0,00	3,00	1,50	1,50	0,00	0,00	0,00	0,00
MassFlow [kg/h]	464,78	446,19	18,59	446,19	356,95	89,24	321,26	35,70	11761,64	7,44
MassFlow [kg/s]	0,129	0,124	0,005	0,124	0,099	0,025	0,089	0,010	3,267	0,002
Density [kg/m³]	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28	0,28
Flow [m³/h]	0,47	0,45	0,019	0,45	0,36	0,089	0,32	0,036	11,77	0,0074
MassFlow H2O [kg/h]	464,78	446,19	18,59	446,19	356,95	89,24	321,26	35,70	11761,64	7,44
MassFlow H2 [kg/h]	0	0	0	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	0	0	0	0	0	0	0	0
Density H2O [kg/m³]	999,126	999,103	999,103	999,243	999,173	999,173	999,103	999,103	999,103	999,103
Density H2 [kg/m³]	0,13	0,09	0,09	0,34	0,21	0,21	0,09	0,09	0,09	0,09
Density O2 [kg/m³]	2,02	1,35	1,35	5,38	3,36	3,36	1,35	1,35	1,35	1,35
Conductivity [µS/cm]	500	500	500	500	8	*High*	0,055	*High*	0,055	0,055
State	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid	Liquid
Min. piping D [mm]	10,5	10,3	2,1	10,3	9,2	4,6	8,7	2,9	52,7	1,3

Water treatment, UPW circulation and O2-production

Stream	Pressurized UPW	UPW to V-201	O2 with UPW	O2 outlet	UPW under press.	UPW to Stack	Return UPW w/O2
Description :	From P-152	From S-161	From V-201/to E-202	From E-202	After P-211	After S-213	After A-231 (anode)
Stream number :	**151**	**161**	**171**	**172**	**211**	**212**	**213**
Temperature [ºC]	64,71	64,71	66,10	25,00	66,10	60,00	66,10
Temperature [ºK]	337,86	337,86	339,25	298,15	339,25	333,15	339,25
Pressure [bar(g)]	4,70	4,20	4,20	4,00	10,30	9,90	4,20
MassFlow [kg/h]	12090,34	12090,34	291,03	283,60	114199,26	114199,26	111934,25
MassFlow [kg/s]	3,36	3,36	0,081	0,079	31,72	31,72	31,09
Density [kg/m³]	0,27	0,27	0,0017	0,0018	0,27	0,27	0,19
Flow [m³/h]	12,33	12,33	47,72	43,53	116,48	116,10	161,62
MassFlow H2O [kg/h]	12090,34	12090,34	8,45	1,01	114199,26	114199,26	111651,67
MassFlow H2 [kg/h]	0	0	0	0	0	0	0
MassFlow O2 [kg/h]	0	0	282,58	282,58	0	0	282,58
Density H2O [kg/m³]	980,91	980,89	980,14	997,23	980,40	983,63	980,14
Density H2 [kg/m³]	0,41	0,37	0,37	0,41	0,80	0,79	0,37
Density O2 [kg/m³]	6,52	5,95	5,92	6,49	12,88	12,65	5,92
Conductivity [µS/cm]	0,055	< 0,055	*N/A*	*N/A*	< 0,055	< 0,055	< 0,055
State	Liquid	Liquid	Gas	Gas	Liquid	Liquid	Liquid
Min. piping D [mm]	53,91	53,91	33,54	32,04	165,72	165,45	195,21

H2 production and treatment

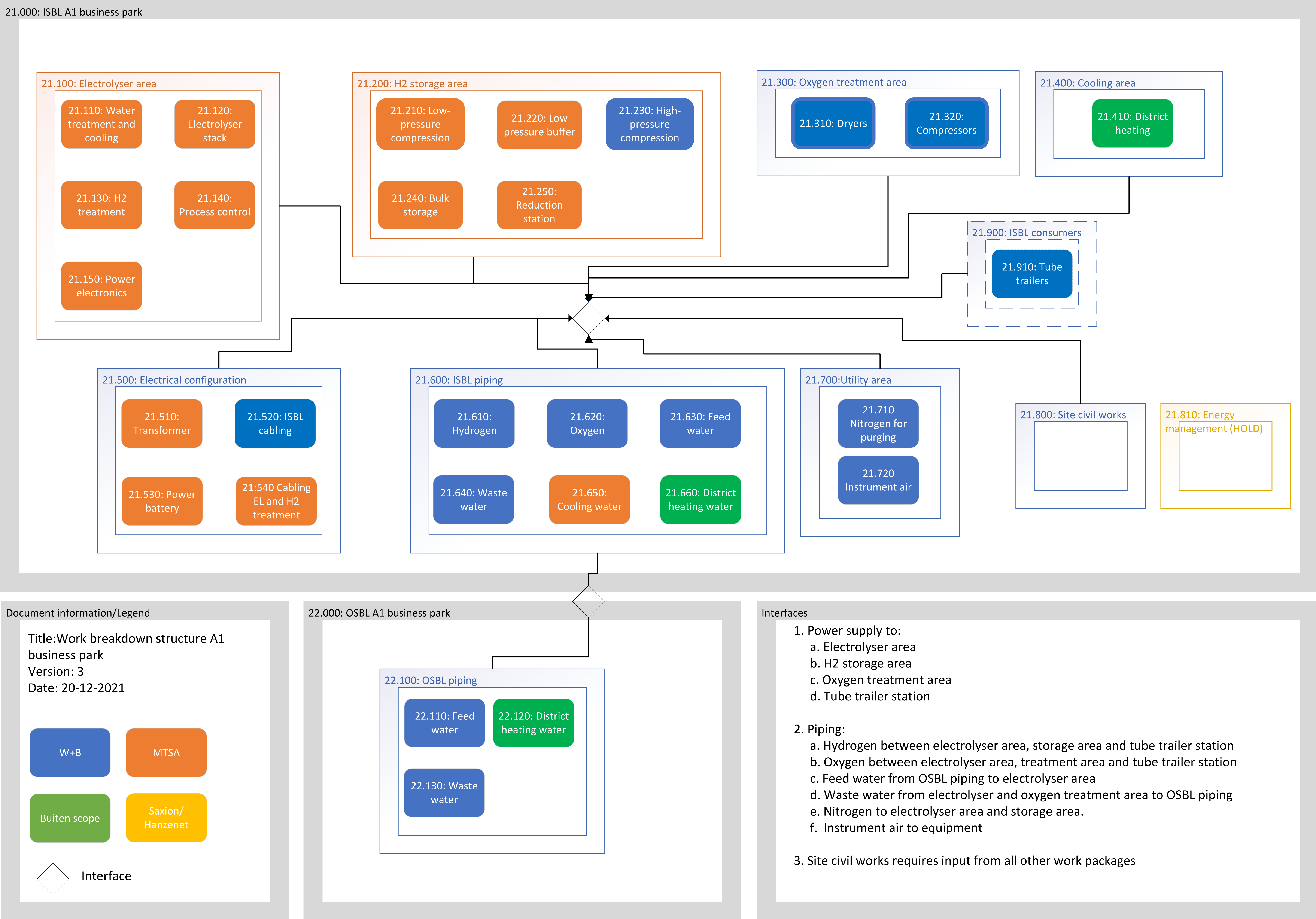
Stream	Sat., wet, hot H2	Return UPW	Saturated, hot H2	Treated H2 (deoxo)	Waste H2O	Untreated H2	Treated H2 (cooled)	Waste H2O
Description :	After A-231/251 (ca)	After V-301	After V-301	After A-321	From A-321	After A-331	After A-341	From A-341
Stream number :	**301**	**311**	**312**	**321**	**322**	**331**	**341**	**342**
Temperature [ºC]	66,10	66,10	66,10	17,55	17,55	66,10	15,00	17,55
Temperature [ºK]	339,25	339,25	339,25	290,70	290,70	339,25	288,15	290,70
Pressure [bar(g)]	40,00	40,00	40,00	38,30	38,30	40,00	39,80	38,30
MassFlow [kg/h]	2265,01	2227,35	37,66	35,60	2,06	37,66	35,74	1,92
MassFlow [kg/s]	0,63	0,62	0,010	0,010	0,00057	0,010	0,010	0,00053
Density [kg/m³]	0,04	0,27	0,00	0,00	0,28	0,00	0,00	0,27
Flow [m³/h]	14,69	2,27	12,42	11,11	0,0021	12,42	10,62	0,0020
MassFlow H2O [kg/h]	2229,40	2227,35	2,05	0,0016	2,06	2,05	0,13	1,92
MassFlow H2 [kg/h]	35,60	0	35,60	35,60	0	35,60	35,60	0,00
MassFlow O2 [kg/h]	0,0062	0	0,0062	0	0	0,0062	0,0062	0
Density H2O [kg/m³]	981,70	981,70	981,70	1000,44	1000,44	981,70	1000,95	1000,44
Density H2 [kg/m³]	2,87	2,87	2,87	3,20	3,20	2,87	3,35	3,20
Density O2 [kg/m³]	47,02	47,02	47,02	53,46	53,46	47,02	56,11	53,46
Conductivity [µS/cm]	N/A	< 0,055	N/A	N/A	N/A	N/A	N/A	N/A
State	Gas	Liquid	Gas	Gas	Liquid	Gas	Liquid	Gas
Min. piping D [mm]	18,61	23,13	17,11	16,19	0,70	17,11	50,05	0,21

Heating and cooling flows

Stream	Coolant in, UPW	Coolant out, UPW	Main cool line	Main cool return	To O2 cooler	From O2 cooler	To deoxo/dryer	m deoxo/dr	To H2 cooler	From H2 cooler
Description :	To E-212	From E-212	From E-351	To E-202	To E-202	From E-301	To A-321	From A-321	To A-341	From A-341
Stream number :	**221**	**222**	**351**	**352**	**353**	**354**	**355**	**356**	**357**	**358**
Temperature [ºC]	55,00	60,00	10,00	25,00	10,00	25,00	10,00	25,00	10,00	25,00
Temperature [ºK]	328,15	333,15	283,15	298,15	283,15	298,15	283,15	298,15	283,15	298,15
Pressure [bar(g)]	6,00	5,60	6,00	4,00	6,00	4,00	6,00	4,00	6,00	4,00
% of glycol in water	0%	0%	10%	10%	10%	10%	10%	10%	10%	10%
MassFlow [kg/h]	139377,76	139377,76	3626,69	3626,69	589,14	589,14	3037,55	3037,55	637,35	637,35
MassFlow [kg/s]	38,72	38,72	1,01	1,01	0,16	0,16	0,84	0,84	0,18	0,18

II

APPENDIX: WORK BREAKDOWN STRUCTURE A1 BUSINESS PARK



Document information/Legend

Title:Work breakdown structure A1 business park
Version: 3
Date: 20-12-2021

W+B

MTSA

Buiten scope

Saxion/ Hanzenet

Interface

Interfaces

1. Power supply to:
   a. Electrolyser area
   b. H2 storage area
   c. Oxygen treatment area
   d. Tube trailer station

2. Piping:
   a. Hydrogen between electrolyser area, storage area and tube trailer station
   b. Oxygen between electrolyser area, treatment area and tube trailer station
   c. Feed water from OSBL piping to electrolyser area
   d. Waste water from electrolyser and oxygen treatment area to OSBL piping
   e. Nitrogen to electrolyser area and storage area.
   f. Instrument air to equipment

3. Site civil works requires input from all other work packages

XII

APPENDIX: EQUIPMENT LIST

Equipment list

Auteur:	Rasyid Salam, Lotte Berkelaar		
Datum:	28-1-2022		life time is based on well-maintained items
Projectcode:	119017		

Area	Equipment name	Description	MTSA or W+B	Design specification (Fill in when in scope of W+B)	Electricity consumption (Fill in when in scope of W+B)	Lifetime	Economies of scale
S-101 Water purification Installation	V-111	Water softener	MTSA			20 years	0,8
	T-121	Break tank	MTSA			20 years	0,8
	P-122	Pump	MTSA			20 years	0,8
	S-123	Reverse osmosis	MTSA			20 years	0,8
	S-124	EDI-cell	MTSA			20 years	0,8
S-221 Circulation water treatment system	T-151	Break tank	MTSA			20 years	0,8
	S-152	Filter and CO2 lock	MTSA			20 years	0,8
	P-152	Pump	MTSA			20 years	0,8
	S-161	Demi catridges	MTSA			1 year	0,8
Electrolyzer	V-201	O2 gas-liquid separation vessel	MTSA			20 years	0,8
	E-202	Heat exchanger	MTSA			20 years	0,8
	P-211	Pump	MTSA			20 years	0,8
	E-212	Heat exchanger	MTSA			20 years	0,8
	A-231/A-251	Electrolyzer stacks	MTSA			40000 hr	unknown
	V-301	H2 gas-liquid separation vessel	MTSA			20 years	0,8
Hydrogen	A-321	De-oxo and dryer	MTSA			20 years	0,8
	V-401	Low pressure buffer vessel	MTSA			20 years	0,8
	A-411	Compressor	W+B	Compression 38.3 bar(g) to 300 bar(g)	253 MWh/year	20 years	0,8
	V-421	Tube trailer	W+B + external party	1 day	n.a.	n.a.	n.a.
Oxygen	A-501	Dryer	W+B	kg/h O2 rated flow pressure: 10 bar	386 MWh/year	20 years	0,8
	V-511	Buffer tank	W+B	15 min residence time 4 bar 284 kg O2 capacity 11 m3	-	20 years	0,8
	A-521	Compressor	W+B	284 kg/h O2 rated flow 55 kW suction pressure: 4 bar discharge pressure: 20 bar incl. motor/piping/intercoolers /KO drums	264 MWh/year	20 years	0,8
Power supply	n.a.	Transformer	MTSA			20 years	0,8
	n.a.	Rectifier	MTSA			20 years	0,8
Utilities	n.a.	Nitrogen supply	MTSA			20 years	0,8
	n.a.	Plant air	W+B	n.a.	n.a.	20 years	0,8

XIII

APPENDIX: DESIGN DOCUMENTS TRADING PLATFORM

Abstract: '*An exploratory study on the integration of a renewable-powered electrolyser in a local energy system*'

HanzeNet, 2021

The current energy transition towards a more sustainable future opens opportunities for new types of energy systems in the Netherlands. A newly proposed system utilises electrolysers to convert locally generated renewable electricity into hydrogen for local industries. This multi-energy carrier (MEC) system serves as a cross-sectional solution to increase the amount of renewable electricity sources and reduce the fossil fuel use of local industries.

An explorative study is conducted to determine how a MEC system could be incorporated in the regulatory framework of the Netherlands and what would be the best design options. A literature review and interviews are conducted to determine how this system can exist within the regulatory framework of the electricity system in the Netherlands. With the results of these in consideration, the design options for both the electricity as the hydrogen part of the MEC system are evaluated.

Furthermore, a case study with a techno-economic analysis is conducted upon the first pilot project, which consists of an MEC system with a microgrid. The inputs and specifications of the local renewable electricity sources (RES), the electrolysers and the hydrogen consumers are used to build three models. These give the opportunity to determine the effect of the addition of hydrogen storage and the addition of dynamic electricity prices on the self-consumption rate and the fuel costs in a MEC system.

The literature review resulted in recommendations on how to incorporate the pre-determined requirements in the MEC system. The resulting recommendations are used to evaluate the proposed design options for both the structure and the market layer of the system. The advantages and disadvantages of each option are qualitatively assessed.

The results of the techno-economic analysis showed that hydrogen storage capacity is maximized to fulfil all the hydrogen demand. The size of the storage capacity is dependent on the flow rate of the electrolyser and the consumption pattern of the hydrogen consumers. The addition of hydrogen storage capacity and dynamic electricity prices to the system lower the fuel cost for hydrogen consumers. Dynamic electricity prices do have a negative effect on the self-consumption rate of the system. This is caused by the low price of a European Guarantee of Origin (GoO) relative to the fluctuations of the electricity price.

XIV

APPENDIX: RECOMMENDATIONS FOR A *MULTI ENERGY CARRIER* (MEC) SYSTEM

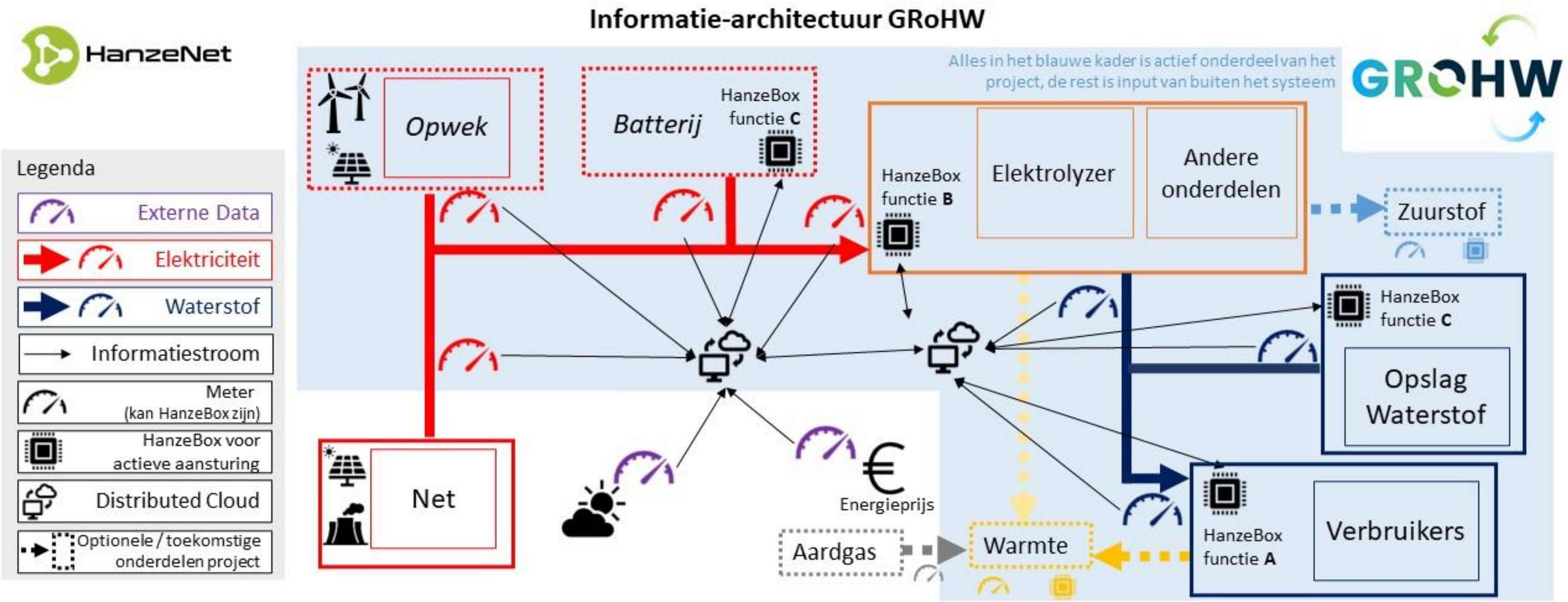
HanzeNet, 2021.

Regulatory requirements	
Requirements	**Recommendations**
Access to dynamic electricity prices	– Join a *Balance Responsible Party* (BRP). A BRP can give the electrolysers access to dynamic electricity prices.
Balancing markets	– Explore the options of providing *Frequency containment reserve* (FCR) and *automatic Frequency Restoration Reserve* (aFFR) services to generate extra revenue for the electrolysers
Connection to renewable energy sources	– Explore the option to create a micro-grid if there are interested parties in the region
Green certificates	– Contract a certificate trader to acquire *Guarantee of Origin*s (GoO) for the electricity that is imported from the grid.
Aggregators	– Explore the option of contracting an aggregator who can provide BRP-, balancing market – and certificate trading services
Hydrogen framework	– Hydrogen trading is done bilateral. There is no hydrogen trading platform active in the Netherlands yet. – Explore the requirements made in the report from the Ministry of Economic Affairs and Climate to be included into the national hydrogen infrastructure.
System requirements	
Technical constraints	– Constraint 1: 24-hour operational requirement of the electrolyser. – Constraint 2: determine the most suitable method for processing the conversion losses of the electrolyser in the trading platform. – Constraint 3: the size of the electrolyser can be a limiting factor if no storage capacity is added to the system.
Demand-side flexibility	– Energy storage capacity and good forecast for supply and demand are essential to profit from dynamic electricity prices. – Demand response activities from hydrogen consumers are not crucial but would provide extra demand-side flexibility.

Design electricity system	
Design	– An administrative connection is always necessary for MEC systems for times of low renewable generation. – A micro-grid would be a valuable addition, but it is dependent on the presence of interested renewable electricity sources.
Trading platform electricity	– In case of an administrative connection, only a power purchase agreement between the electrolysers and the BRP or aggregator needs to be made. – In case of a microgrid, a power purchase agreement must be made between the electrolysers and the renewable electricity sources. – Explore if it is desirable that an aggregator takes over the electricity trading activities.
Design hydrogen system	
Design	– An electrolyser owned by a third party is the better configuration for the hydrogen system compared to the situation where an electrolyser is in shared ownership of the hydrogen consumers, since the latter has a higher chance of conflict.
Trading platform hydrogen	– Bilateral contracts are an easy and reliable solution for the hydrogen system. However, the system is less scalable than a marketplace. This reduces the expansion possibilities of the system in the future. – An open marketplace can be an option. This option is more scalable. However, there are some bottlenecks in terms of uncertainty among hydrogen consumers and market power of the electrolyser owners.

XV

APPENDIX: INFORMATION-ARCHITECTURE IMPRESSION



Scenario's
Er zijn meerdere scenario's waarvoor slimme aansturing relevant is:

Uitgangspositie
- Bij een waterstofbehoefte zijn vier bronnen (indirect) aanspreekbaar: Opslag waterstof, batterij, eigen opwek en het energienet, waarvan de laatste 3 via de elektrolyzer. Afhankelijk van de energieprijs(verwachting), de actuele weersverwachting en randvoorwaarden van de apparatuur bepaalt het systeem welke bronnen in welke mate worden aangesproken om zo optimaal mogelijk te voorzien in de waterstofbehoefte.
- Dit systeem maakt het mogelijk om de afname van waterstof enigszins flexibel te houden. Binnen een bepaalde bandbreedte kan een afnemer zijn vraag aanpassen en het systeem kan daar de productiestrategie van de waterstof op aanpassen.
- Het terugleveren van eigen opwek aan het energienet is minder voordelig dan die energie gebruiken om waterstof te genereren (aanname).

Voorbeelden
A. Wanneer de zon schijnt, er sprake is van eigen opwek en er op korte termijn geen waterstofbehoefte is vult de elektrolyzer de waterstofopslag.
B. Als er geen of nauwelijks eigen opwek is en tegelijk een lage actuele energieprijs, wordt de waterstofopslag toch gevuld via de elektrolyzer zodat er later minder waterstof geproduceerd hoeft te worden.
C. Als er waterstof opgeslagen is en een afnemer meer waterstof nodig heeft dan in eerste instantie gepland, is er ruimte voor flexibiliteit binnen een bepaalde bandbreedte.
D. Als eigen energie opwek fluctueert kan de elektrolyzer deze fluctuaties mogelijk niet gelijk opvangen omdat deze tijd nodig heeft om op- of af te schakelen. In dit geval zou een (kleine) batterij ingezet kunnen worden als buffer om deze fluctuaties op te vangen. Deze batterij moet dus altijd enige capaciteit beschikbaar hebben.

Toelichting HanzeBox functies::
Taken HanzeBox functie **A**:
1. Energiebehoefte doorgeven
2. Aansturen lokale apparatuur (toekomst)

Taken HanzeBox functie **B**:
1. Aansturen elektrolyzer op basis van energiebehoefte

Taken HanzeBox funtie **C**:
1. Doorgeven beschikbare energie en – capaciteit
2. Aansturen opslag

GRoHW fase 1 (nu)

We brengen de eisen van een *slim, decentraal* en *robuust* multi-energy systeem in kaart en simuleren centraal hoe dit kan werken.

GRoHW fase 2 en 3

Hoe kunnen we een *slim*, *decentraal* en *robuust* multi-energy systeem optimaal aansturen waarbij eindgebruikers/ stakeholders regie houden over hun eigen verbruik (en opwek) en apparatuur. Dit wordt in de praktijk getest en vervolgens opgeschaald.

Aansluiten apparatuur op HanzeBox
Om een batterij, meetinstrument, elektrolyzer of ander apparaat op een HanzeBox aan te sluiten moet die aan de volgend eisen voldoen:
- Aansluitbaar via usb, bluetooth of wifi
- Communiceren via een gespecificeerd protocol

Datastromen

Meters
- 'Flow' meters:
  - Elektriciteit: afname/teruglevering
  - Waterstof: afname/teruglevering
- Externe Data
  - Weer (voorspellen elektriciteit opwek)
  - Elektriciteitsprijs

Actieve aansturingen
- Waterstofbehoefte (input van verbruikers)
  - Verwacht verbruik van verbruikers, marges waarbinnen die dit verbruik mogen bijstellen, ...
- Opslag capaciteit/beschikbaarheid
  - Laadsnelheid en ladingvastheid opslag, ...
- Setpoints electrolyzer
  - Snelheid op/afschakelen elektrolyzer, efficiëntie bij bepaalde last, ...

Voor slimme en efficiënte actieve aansturing is het nodig om de randvoorwaarden te inventariseren.

XVI

APPENDIX: MVP TRADING PLATFORM

Figure XVI.1 Timeline of a single trade-interval

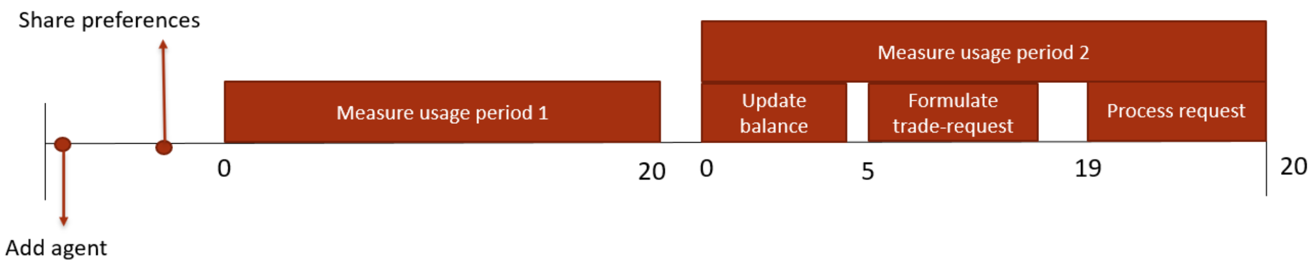


Figure XVI.2 An agent dashboard, with editable trade-preferences

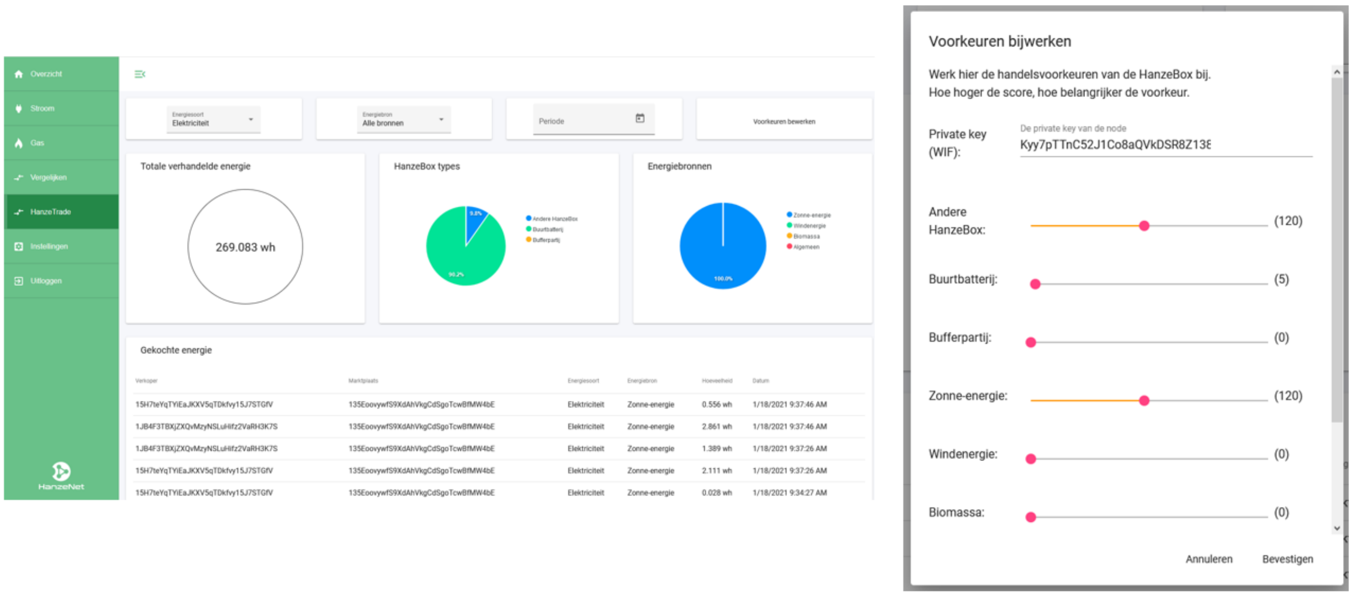


Figure XVI.3 Global dashboard