H2 Energy storage/bunker Island

in the Dokhaven

Track building technology

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Chapter 1
Research Framework

1.1 Background and relevance

The European end overall energy consumption of the current energy structure covers their energy demand of transport 31,6% (Europe, 2013), households 26,8%, industry 25,1%, services 13,8% and agricultural fishing and forestry 2,7% (EEA, 2013). The present high efficiency and low cost integrated renewable energy generation technologies are advancing towards a transition to distributed energy systems. As result of an increase use of hybrid vehicles, sharing economy of transport and urbanization, the communities are becoming centralized, whereby the related energy systems becomes decentralized (González-Gil, A., et al., 2014). This falls under the zero-energy concept, whereby energy systems produce as much renewable energy to balance the demand. The European Parliament pleads that each new building is obliged to be nearly zero-energy buildings (nZEB) from the year 2021 (The European parliament, 2010). To further elevate the zero-energy concept, building and transportation are integrated, where the energy exchange between these is trivial (Li, DHW., et al., 2013). One approach to increase the efficiency of is the development of micro grid power systems. Different types of renewable energy sources, energy generators, storage devices, charging station for transport can be applied in this system to achieve an optimized energy design. The micro grid energy system can be connected to the utility grid to guarantee of the energy supply during emergencies. This offers more reliability of the energy supply and reduces the transmission losses.

1.2 Problemstatement

Transport

According to CBS (2015), approximately 20 percent of the total carbondioxide (CO2) emissions in the Netherlands is caused by transport. CO2 emissions are directly connected to the consumption of fossil fuels. Although, transport by road may have the largest CO2 emission (51%) of the total transport emission. The Inland shipping still have emission of an impact of 5,1% and the international shiping 15,3% of the total emission.
Inland shipping is planning want to reduce the emitted greenhouse gas CO2 with 20% by 2030. The sector have signed an agreement with Minister Cora van Nieuwenhuizen of Infrastructure and Water Management. Due to the sustainability, inland shipping should remain competitive with freight transport by road and rail. The ultimate goal is to be climate neutral by 2050 (Mainport, 2018).

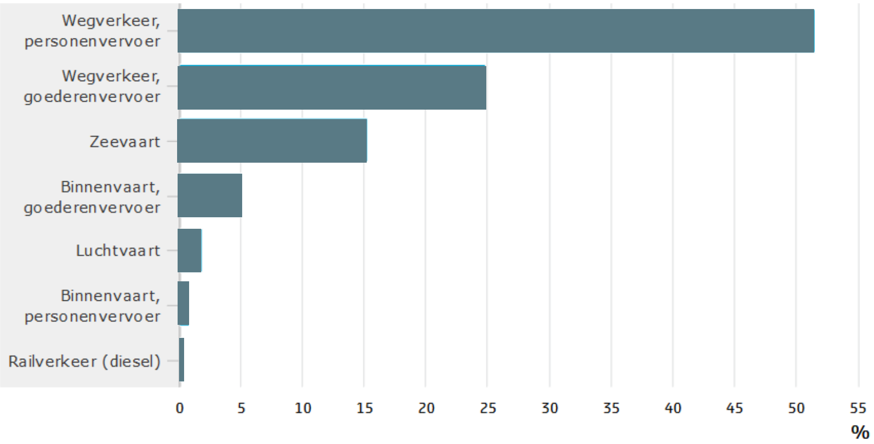


Fig. 1.1, Emission of carbon dioxide by transport, according to CBS (2015), retrieved from: https://www.cbs.nl/nl-nl/maatschappij/verkeer-en-vervoer/transport-en-mobiliteit/energie-milieu/milieuaspecten-van-verkeer-en-vervoer/categorie-milieuaspecten/kooldioxide

Building

Solar panels and wind turbines are the fastest-growing renewable energy sources globally. Between 2008 and 2013 the average price for solar panels has dropped 50% and for wind turbines 35%, stated by International Energy Agency (2014). However, complete energy-sufficient buildings are seldom built, due to the variable and seasonal nature of the systems. The generated energy is not consistent enough to provide for the energy demand during certain times. Another reason why buildings are not completely energy self-sufficient is that there are limited energy storage options. Typically energy is stored in batteries that have a decent efficiency, however the required battery systems are very heavy and contain metals that are harmful for the environment.

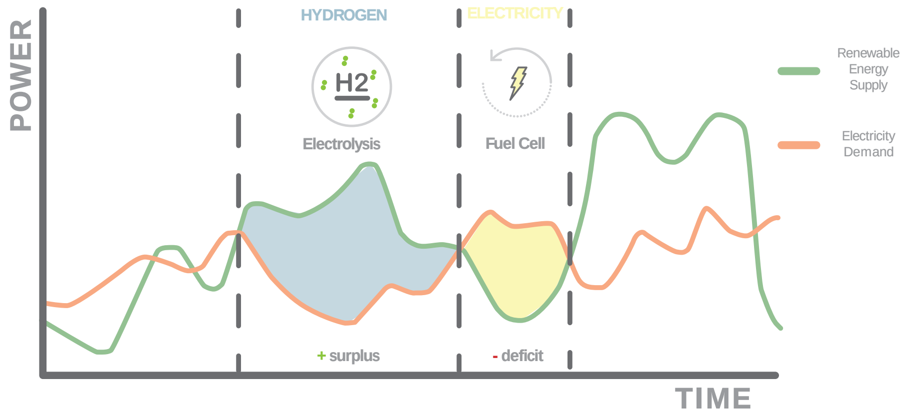


Fig. 1.2, If there is an excess renewable energy generation, hydrogen will be produced and stored. When there is a deficit renewable energy, the stored hydrogen is converted to electricity.

1.3 Overall objective

The overall objective of this study to create an Island which is energy self-sufficient with a hydrogen storage and bunker station, together with public functions. These different functions should be integrated and be part of the overall architecture and represent ‘clean energy for the future’, together with a efficient and safe structure. The main challenge is to develop long-term and short-term energy storage methods that are practicable to assist the balance between the energy demand and supply. The island should generate enough hydrogen, to provide reliable power for the building and transportation. Shipping will be compelled to adopt to the provided hydrogen bunker station. Impact on the environment from the shipping will be decreased by converting traditional diesel powered ships into hydrogen powered ships. Safety must be ensured for the public, in particular the parts where hydrogen is involved.

To overcome the inconsistency of energy production and demand, energy storage is required to bridge a certain period, to provide reliable energy to power buildings and mobility year-round. Hydrogen as an energy carrier is a clean and sustainable option, assuming that it is produced from renewable energy. Some even believe it is the clean fuel for the future. It is used for many operations, but most of hydrogen produced today is used in the petrochemical sector and for manufacturing fertilizers but not often for energy storage in buildings, districts or transport.

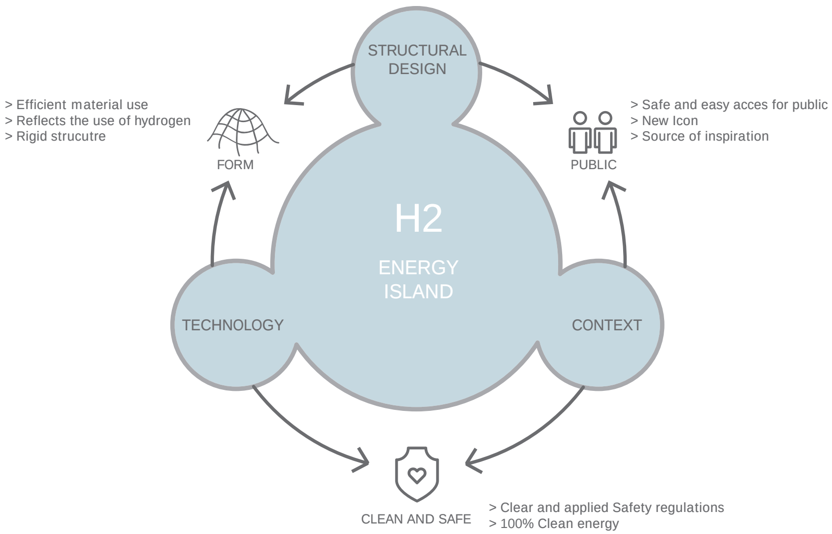


Figure 1.3, Overall objective scheme

From the problemstatement and the overall objective research questions can be formulated. The main research question is formulated as following:

"How to design an integrated, safe hydrogen storage and bunker station, together with public functions on an island near the RDM terrain?"

Energy system approach and methodology

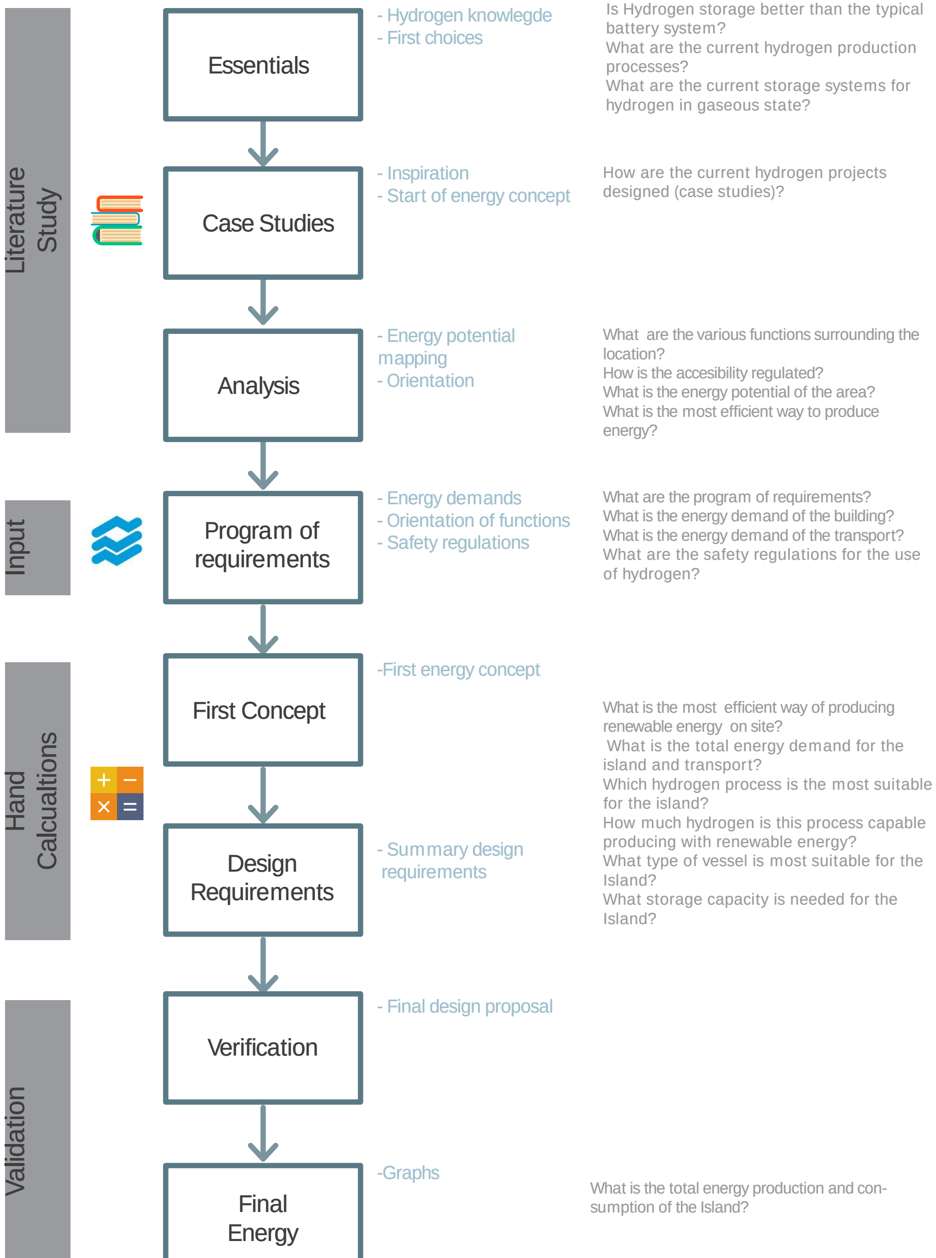


Figure 1.4, Schematic approach energy system

1.4 Energy system objective

The objective is to develop long-term and short-term energy storage solutions that are practicable to assist the balance between the energy demand and supply. Therefore the island must generate hydrogen efficient as possible, to provide reliable power for the building and transportation. It is essential that the Island is powered by "clean" energy. The aim is that the public functions should be completely energy self-sufficient, meaning that the building can be powered off grid, by renewable energy sources and thereof produced hydrogen.

From the problem statement and objective the first research question can be formulated. The research question is formulated as following:

" What is the most functional and safe hydrogen system for the Island located near the RDM terrain"

Approach and methodology:
In order to answer this first research question mentioned above, the essential information of hydrogen will be collected and case projects will be studied. With the results of this literature study and the requirements, the energy concept will be made, evaluated by experts and tested through hand calculations.

Structural design approach and methodology

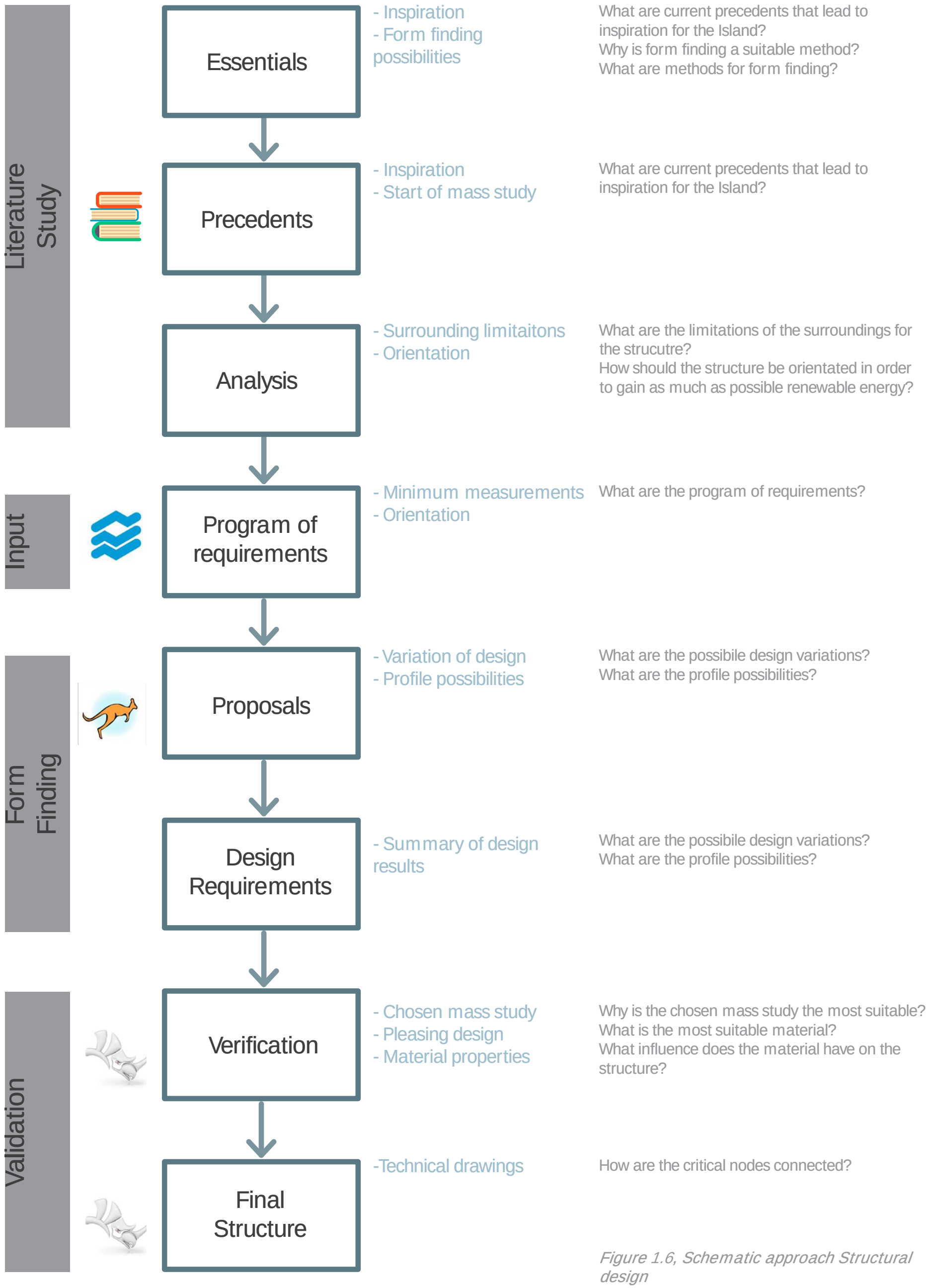


Figure 1.6, Schematic approach Structural design

1.5 Structural system objective

The hydrogen fuelling station and research centre should be a showcase of the hydrogen energy system. One of the relevant property of hydrogen is the low density and according to some scientist, hydrogen can serve as an energy carrier for the future, the design should be a reflection of these two main points. Not only should the design be aesthetically pleasing, but also efficient, by means of lightweight, form and shape, durability and material usage.

From the problem statement and objective the second research question can be formulated. The research question is formulated as following:

"*How can an integrated and efficient structure be designed that is suitable for the hydrogen system?*"

Approach and methodology:
In order to answer this second research question mentioned above, first precedents will be studied and an analysis of the location will be made and then form-finding study will be performed. Starting off with proposals (Grasshopper and Kangaroo), together with the hydrogen system. This will be evaluated by experts in the field. With the results a final design requirement summary will be made and the final design will be further elaborated. With the goal to find an efficient structural form and grid-configuration of a grid shell structure combined with the most suitable material, within the restrictions set by the context and architectural design (Karamba). Using the findings of this process and the final form, details for the grid shell will be drawn.

Chapter 2
Introduction to hydrogen

2.1 Properties of hydrogen

Hydrogen is a odourless, colourless gas that have a lower density than air. Making use of odorant to detect leaks is under development (CP4, 2012). Nevertheless, the current odorants are rejected, due to the possibility of adversely affect to the fuel cell membrane catalysts. Additionally, these chemicals can have limited effect for small leaks, because the odorant molecules are larger than the hydrogen molecules. The properties of hydrogen are notably different from the more typical fuels. Therefore it is essential to take this into considerantion, when constructing and installing a hydrogen system. In table 2.1, the properties of conventional fuels, methane and propane, are compared to hydrogen (Wikipedia, 2017).

Properties	Hydrogen	Propane	Methane
Density (kg/m^3)	0,090	1,88	0,65
Diffusion coefficient in air (cm^2/s)	0,61	0,12	0,16
Molar mass (g/mol)	2,02	44,10	16,04
Viscosity (g/cm-s*10^{-5})	0,083	0,819	0,651
Melting point (K)	14	86	90
Boiling point (K)	20	231	112
Auto ignition temperature (K)	858	760	813
Specific heat at constant press. (J/gK)	14,89	1,56	2,22
Flame temperature in air (K)	2318	2198	2148
Detonability limits (vol % in air)	13 - 65	3,1 - 7,0	6,3 - 13,5
Maximum burning velocity (m/s)	2,6	0,47	0,43

Table 2.1. Properties of hydrogen, propane and methane, Retrieved, December, 13, 2017, from https://en.wikipedia.org/wiki/

2.2 Pros and cons of hydrogen

Advantages

Hydrogen is the most occuring element and it consist 75% in the universe and it plays an essential role in the sustainability life. Meaning that there is no chance of running out like other energy sources. Aside from allowing other species to survive, hydrogen can be exploited into energy.
Hydrogen is a highly efficient energy type, it has the capability to transmit a lot of energy for every pound of fuel. This is due to the high density of hydrogen (120MJ/kg) compared to natrual gas (50MJ/kg). Hydrogen energy’s and power capacity allows a diverse applicability. For

example it is an ideal fuel source for spaceships.
The byproducts through combustion of hydrogen are completly safe, they have no side effects on health or harm the environment. After the combustion it is possible to convert it into drinking water. From a economic point of view dependence on gas or oil producing countries will decrease (Rinkesh,2012).

Fig. 2.1. Hydrogen advantages

Disadvantages

Above mentioned the excellent advantages of hydrogen, however it is still not a conventional energy carrier. The main reason why hydrogen is used widely across the world is that it is awfully expensive. There are still challenges required concering affordability and sustainability to harness this form of energy.
Hydrogen have to be compressed to liquid state and at a particular temperature to assure its efficiency and effectiveness as an energy source. This means it must be stored under pressure at all times, therefore special storage and safety applications must be guaranteed. The same applies to transporting hydrogen and it is moved in small amounts most of the time. Handle with care is needed due to the highly flammable and even explosive properties of hydrogen. Compared to gas it is odourless, that makes it more difficult to detect leaks (Rinkesh,2012).

Fig. 2.2. Hydrogen disadvantages

2.3 Hydrogen storage compared to battery

One way of producing sustainable hydrogen is through electrolysis. It can be assumed that hydrogen electrolysis has an efficiency of 80%. However it still have to be converted into electricity. The fuel cell which converts hydrogen to electricity usually efficiency of 50%. The entire efficiency of the hydrogen is around 40%. The system of a battery storage is much simpler and therefore less efficiency loss through the components. The only loss that can occur is the battery, which is around 20%.

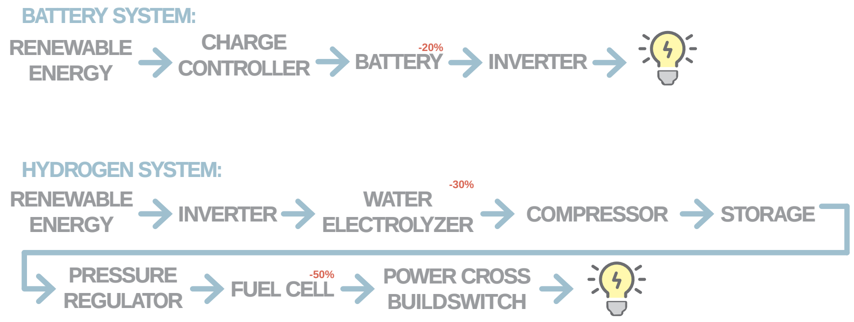


Fig. 2.3 Hydrogen storage compared to battery scheme

Applying a battery system combined with solar panels is a lot more efficient than hydrogen storage and does not have the safety complications. However, using hydrogen storage is still preferred, due to the heavy metals of the battery causing harm to the environment.

2.4 Hydrogen production methods

Introduction

At this moment there are a variety possibilities of producing hydrogen. These processes are at different scales of development and some are more conventional. Below an overview is given of the different production procceses with a short description, pros and cons and further challenges (EERE, 2017 & IEA 2006).

Steam-methane reforming

This natural gas reforming contains endothermic conversion of methane and steam into carbon monoxide and hydrogen. 95% of the hydrogen produced in the United States is made by natural gas reforming. Combustion of the methane will provide for the required heat, this is generally around 700ºc to 850ºc and pressures of 3 to 25 bar. After the reforming result is 90% hydrogen and 10% carbon monoxide, the carbon monoxide will be converted into carbon dioxide and hydrogen through water-gas shift reaction.

STEAM-METHANE REFORMING REACTION:

$CH_4 + H_2O$ (+ heat) → $CO + 3H_2$

WATER-GAS SHIFT REACTION:

$CO + H_2O$ → $CO_2 + H_2$ (+ heat)

PROS
+ High efficiency
+ Costs for large units

CONS
- Use of natural sources
- Green house gasses
- Complex system
- Sensitive to gas qualities

Coal gassification

Coal gassifiction is a method that can not only produce hydrogen but also; produce power, chemicals and liquid fuels.
Same as steam-methane reforming, producing hydrogen, additional heat is required (endothermic). Hydrogen is produced by reacting coal with oxygen under high temperature and steam to form synthesis gas which contains primarily of hydrogen and carbon monoxide. After filtering the impurities in the gas, the same water-gas shift reaction is used to react with the carbon monoxide to produce additional hydrogen.

Biomass gassification

This form of biomass gassification is a process that converts fossil or organic based, carbon containing materials at high temperatures together with oxygen and steam into carbon monoxide hydrogen and carbondioxide. After the reaction the carbon monoxide will be processed further with the water-gas shift reaction.

SIMPLIFIED BIOMASS GASSIFICATION REACTION:

$CH_4H_{12}O_6 + O_2 + H_2O$ → $CO + CO_2 + H_2$ (+ impurities)

WATER-GAS SHIFT REACTION:

$CO + H_2O$ → $CO_2 + H_2$ (+ heat)

PROS
+ Demestic resource
+ “Recycles” CO_2

CONS
- Feedstocks are unrefined
- Green house gasses
- Complex system

Introduction water electrolysis

Hydrogen can be produced from splitting of water through a variety of processes. These are efficient and economical procceses that would be key technological components of a hydrogen economy. Electrolysis is a promosing process for hydrogen production from renewable resources. Water electrolysis is a process whereby water is split into hydrogen and oxygen through electricity. The reaction takes place in the electrolyser. This process will be more efficient the temperature is slightly increased, therefore it might be preferable to use available waste heat. Electrolysers size can range from small to large, it is suited for smale distributed hydrogen production to large scale. A short description of these processes will be given below.

Polymer Electrolyte Membrane Electrolyzers

PEM electrolyser uses a solid electrolyte, which is an acidic polymer membrane and by not using a liquid electrolyte will simplify the design. The water reacts at the anode to form oxygen and positive charged hydrogen. The electrons flow through an external circuit and the hydrogen ions selectively move across the PEM to the cathode. At the cathode, hydrogen ions combine with electrons from external circuit to from hydrogen gas.

ANODE REACTION:

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

CATHODE REACTION:

$4H^+ + 4e^- \rightarrow 2H_2$

PROS
+ Renewable source
+ Zero greenhouse gas
+ Highly promosing

CONS
- Relatively high cost
- Short lifetime

Alkaline electrolysis

Alkaline electrolysers makes use of a liquid alkaline solution of sodium or potassium hydroxide. This solution circulates from the cathode to the anode with hydrogen being generated on the cathode side. Alkaline electrolysis is a further developed technology, with a high amount of industrial applications.

ELECTROLYTE REACTION:

$4H_2O \rightarrow 4H^+ + 4OH^-$

ANODE REACTION:

$2H_2O \rightarrow O_2 + 4H^+ + 4e^-$

CATHODE REACTION:

$4H^+ + 4e^- \rightarrow 2H_2$

PROS
+ Renewable source
+ Zero greenhouse gas

CONS
- Relatively high cost
- Short lifetime
- Low turn-down ratios

Thermochemical water splitting

By using Thermo-chemical water splitting, the water is converted into hydrogen and oxygen by an array of thermally chemical reactions. This method has variable conviences, potential for high efficiency and low cost, however it have been of little interest for the last ten years.

An example of this thermochemical process is the copper chloride cycle, this is a more complicated cycle, however they require a lower operating temperature compared to the less complicated hybrid cycles.

DISSOCIATION:

$4Cu_2OCl_2 \rightarrow 2CuCl + 1/2O_2$

HYDROLYSIS:

$2CuCl + H_2O \rightarrow 2Cu_2OCl_2 + 2HCl$

ELECTROLYSIS:

$2CuCl + 2HCl \rightarrow 2Cu_2Cl_2 + H_2$

NET REACTION:

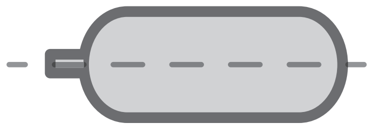
$H_2O \rightarrow 1/2O_2 + H_2$

PROS
+ Renewable source
+ Near zero greenhouse gas

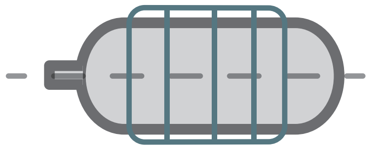
CONS
- Durability of reactant materials
- Low efficiency of reactor
- Expensive mirror system

2.5 Hydrogen storage in gaseous state

Hydrogen in gasesous state is commonly stored under compression, due to the extremely low density of 0,084kg/m². The energy content of the gas at ambient temperature and pressure is 10MJ/m³, which requires a very large volume for hydrogen storage (Srivastava O. N., 2016). The thickness of the container walls, size and weight, materials and costs depends on at what pressure the hydrogen is stored. There are four types of hydrogen tanks developed:



Type 1



Type 2

Fig. 2.4 The four different types of hydrogen vessels

Type 1 vessels are seamless containers made of aluminium or steel. They have thick walls and are extremely heavy, but relatively cheap storage option for stationary applications. However, these containers cannot withstand pressures higher than 50MPa. The type 2 vessels have seamless metallic tanks hoop-wrapped with fibre resin. Same as type 1, these vessels are also heavy, but can withstand pressure up to 80MPa. The costs are still competitive due to a relatively low number of fibres used.
Type 3 and 4 have thinner walls and are lighter compared to type 1 and 2. Type 3 withstands pressures up to 45MPa have seamless or welded aluminium liners fully wrapped with fibre resin composite. Type 4 are made of plastic liners in a epoxy matrix, the fibres wrapping provides the strength to withstand pressure of 70MPa. Despite having a lighter weight, they are still more expensive (Tretsiakova-Mcnally S., 2015).

Type vessel	max. Pressure	Technology maturity	Weight performance	Weight performance
Type 1	50MPa	++	-	++
Type 2	not limited	+	0	+
Type 3	70MPa	+	+	-
Type 4	100MPa	--	++	-

Table 2.2. Summary of the four types of hydrogen vessels

2.6 Methods of of refilling hydrogen

Presumably, the hydrogen production on site is not adequate for the peak demands of the Island. Additionally with a long term perspective on the increase of hydrogen usage, in particular the transportation, a solution should be formed to equalize the hydrogen and its demand. This can be done in various approaches, divided in two main approaches direct hydrogen and in-direct substitution.

Direct

By direct substitution, the surrounding area is analysed for a proper hydrogen production plant. The hereby produced hydrogen is placed in mobile vessels and transported to the Island by truck. The hydrogen can directly fuel the ships, by a fuelling station or the entire mobile vessel can be lifted onto the ship. This substitution is a simple solution the meet the hydrogen demand. However, the primary downside is that hydrogen have to be transported to location. Depending on the distance and production method of the hydrogen station, will lead to emission of greenhouse gasses of especially transportation, resulting into a not completely clean hydrogen.

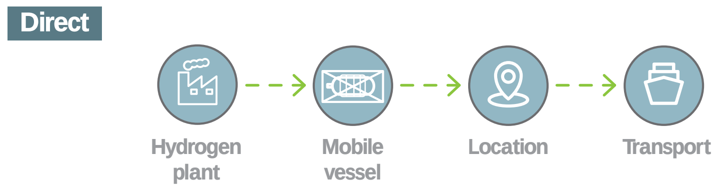


Fig. 2.4 Direct substiution through mobile vessels

Second method of direct substitution, also include a surrounding hydrogen production plant. Instead of transporting the hydrogen by truck, the station is directly connected though underground piping, and stored in the stationary vessels on site. Resulting in fast and most efficient way of transporting hydrogen and zero-greenhouse gasses through the absence of transportation. Major downside of this method is that it is a huge intervention, that will take a long time and cost a lot compared to mobile transport. Nonetheless, this subitution applicable for a long-term perspective, large scale projects. For example, H21 project (2016, Leeds City Gate), is a study with the objective of determining the feasibility, from both a technical and economic viewpoint, of converting the exsisting natural gas network in Leeds, one of the largest UK cities, to completely hydrogen.

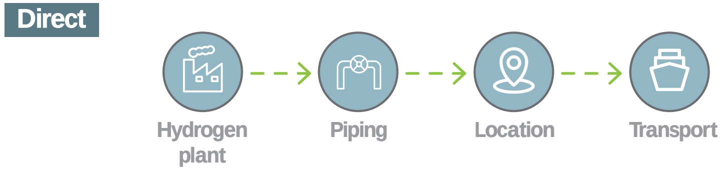


Fig. 2.6 Direct substiution through piping

Indirect

By in-direct substitution electricity, preferably from renewable sources, is taken from the grid to power the electrolyser to reach a higher production rate of hydrogen, when the generated energy on the Island is not consistent enough. This ensures a stable hydrogen production even during peak demands. This is efficient way of balancing the difference, if the energy system is connected to the grid only small interventions are necessary. Drawbacks are the maxium production of hydrogen is still limited by the installations on site.

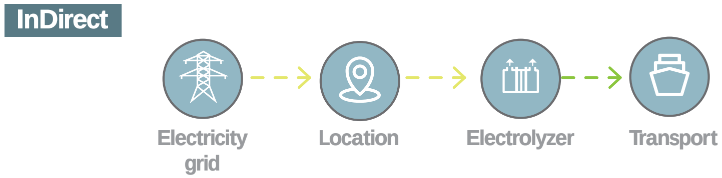


Fig. 2.7 InDirect substiution through production on-site

2.7 Handle hydrogen with care

Introduction

Similar to other fuels, hydrogen must be handled responsibly. Like natural gas and gasoline it can be dangerous under specific conditions, therefore it is important to understand its behavior. However, there are different requirements, hydrogen is currently considered as a chemical and not as yet as a fuel. Hydrogen is colorless and odorless, a person will not be able to detect it. For that reason industries apply sensors to help detect leaks. On the contrary hydrogen is a bit harder to combust, compared to other flammable fuels, due to the diffusivity and small molecular size. To ensure safety it is crucial that the following measurements are taken into account (Rivkin C., Burgess R., and Buttner W., 2015)

Installation location

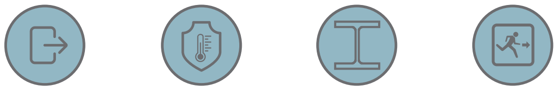
The hydrogen system should be protected against unauthorized acces, vandalism or terrorist attack. For indoor installations, the hydrogen system should be stationed in a normally unoccupied, well ventilated space built of appropriate fire-resistance standard and minimised combustible materials. Making use of proper protective appliances for openings (e.g. shutters, service entries, doors, windows, etc.) should be considered. Openings or voids between the areas where the hydrogen system is stationed should be avoided and the separating walls should be gass-tight. The installed automatic fire detection, alarm and suppression system should be checked whether it is correctly specified for the room, where the hydrogen system is located.

Ventilation

Mechanical or natural ventilation can be applied to prevent the formation of possibly explosive compouds. The preferred method is natural ventilation because of its intrinsic reliability. Clean air intake should be provided, so the hydrogen system is not affected by other gasses or contaminants. Furthermore the exhaust of the ventilation or other emission of possible dangerous gasses should be released to a safe place not directly towards walkways of pedestrians. A proper hazardous zone should be pinpointed around any accountable release points.

Outdoors

Where functional, especially for industrial applications, the hydrogen system should stationed outdoors, therefore weather protection is necessary. Hydrogen storage vessels stationed outdoors should be protected from extreme temperatures (below 20ºc and above 50ºc). Hydrogen vessels that are installed permanently should be provided with steady supports, assembled of non-combustible materials and firmly anchored to the foundations, that are protected from accidental impacts, this also applies to transportable compressed gas vessels. The area around the hydrogen installation must be free of dry vegetation and combustible substances. Only weedkillers that are not a potential source of fire hazard can be used, other chemicals such as sodium chlorate should not be chosen for this purpose. Additionally all the components of the hydrogen system should not interfere the building exits, under normal circumstances or emergencies.



Lighting Protection

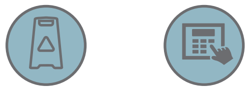
Hydrogen installations that are stationed outdoor should be provided protection against lighting strikes. This can be achieved by installing a system for conducting the resultant electrical charge to earth and also ensuring all equipment is electrically bonded and grounded.

Materials selection for installation

Materials used for the installation of the hydrogen system must be suitable for such application during the anticipated lifetime except recplacement is prepared for. Where mandatory, acceptable protection against chemical attacks or corrosion must be provided, taking into account the intended and reasonably foreseeable use. Every plausible cause of ignition, for example non-flameproof electrical light fittings, should be positioned below any appliances from which hydrogen can leak and not impenetrable ceilings where possible accumulation of hydrogen.

Tripping, slipping or falling risks

Acces to the appliances should not have any possibility to trip, slip or fall for workers delivering supplies or performing maintenance. Enclosures or rooms containing appliances should be equiped with measures to prevent a worker from being accidentally trapped within it or with the possibility of summoning help.



Maintenance requirements

Equipment maintenance

Maintenance and modification points must be located in safe zones. The worker should be able to carry out modifications, repair or cleaning while the equipment is paused. When there are automated appliances, a connecting apparatus for diagnostic error-finding should be installed. The components that have to be replaced periodically, should be done in a safe and easy way.

Access to maintenance points

Appliances should be constructed and designed in a way that allows safe access to all areas where intervention is needed during operation maintenace and adjustment of the equipment.

Cleaning of internal parts

The appliances must be constructed an arraged in the that it is possible to clean the internal parts that have been effected by dangerous substances, any unclogging must be possible from the outside. Assuming that this is not possible, it still have to be contructed in a way that allows the cleaning to be safe.

Chapter 3
Case studies

3.1 Production configurations with renewable energy

Different renewable energy production such as wind turbines, solar panels and hydropower are capable to produce hydrogen in diverse utilizations. These can be divided into two main utilizations, autonomous (off-grid) and grid-connected (on-grid) by Sherif S., Barbir F., Veziroglu T., (2005). Off-grid utilizations are when the electrolyser and renewable energy production are not connected to the main electricity grid. The produced hydrogen is hereby completely renewable. Depending on the components of the off-grid, two main configurations may follow from this utilization, noted as Off-A and Off-B.

In the Off-A configuration, solar panels and wind turbines are linked with the electrolyser to produce hydrogen only. In this configuration, the performance of the electrolyzers are immensely fluctuating, due to changeability of the solar and wind resources. The connection of the renewable energy systems may implemented by means of a dc/dc power converter unit for solar panels and for wind turbines an ac/dc or d/c can be used. Through these power optimizer units, the generated current and voltages by renewable energy system are conditioned into suitable values for the fuel cell. Additionally, tracking is possbile to detect the maxiumpower each moment. On the other hand, electrolyzers operate at high currents and low voltages combined with the intermittency of renewable resources, reduces the efficiency of optimizing units at a maximum of 70%. Occasionally, this can be avoided by not applying the optimizer unit and connected the fuel cell directly to the renewable energy system. For solar panels involves designing the generator to match the electrolyser.

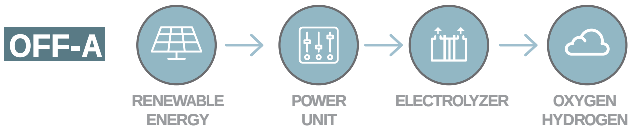


Figure 3.1. Scheme OFF-A configuration

The Off-B configurations are autonomous systems that integrate hydrogen storage and fuel cells to supply energy to demand of small grids placed in distant areas where there is no acces main electricity grid. Regarding these systems, the excess renewable energy not utilized by the small grid, is used to produce hydrogen. The produced hydrogen is stored, later when the small grid demands more than the renewable energy system can produce, the hydrogen will be converted into electricity through the fuel cell. The excess hydrogen can also power other applications, such as vehicles, house heating, etc. The power control system should be able to control the energy flow between the produced renewable energy, the demand, electrolyzers and the fuel cell. This configuration pratically includes a hybrid combination of solar and wind generators for a higher utilization factor of the complete system. The alternative On-grid utilizations, unlike the Off-grid utilizations, are defined by that the renewable energy and electrolyzer systems are both connected to the main electricity grid. Two main configurations may follow from this utilization, noted as On-A, and On-B.

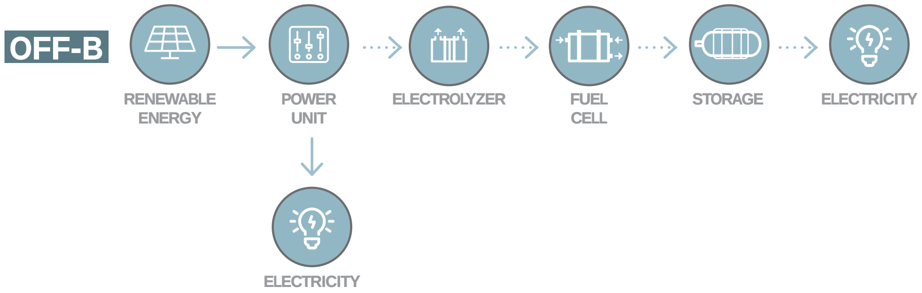


Figure 3.2. Scheme OFF-B configuration

In configuration On-A, the generated renewable energy is directly fed to the main electricity grid at all times. The operating electrolysis system is constantly powered, which is related to the average electric produced by renewable energy system, along with no fluctuations. This assures a steady operating electrolyser without depening on solar radiation variability and wind speed. The main electricity grid functions as a virtual storage that balances the electricity generated by the renewable system.

The efficiency of the electrolysis system can almost reach 100%, as result reducing the costs of hydrogen production. The primary drawback is that operating electrolyzer not always powered by renewable energy, therefore the produced hydrogen is not completley renewable.

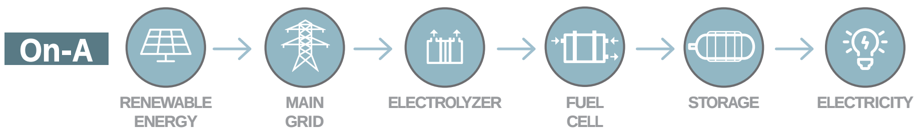


Figure 3.3. Scheme ON-A configuration

In configuration On-B the electrolysis system is only supplied by the renewable energy system, producing completely renewable hydrogen. The excess energy which is not used for producing hydrogen will be injected to the main electricity grid. The activity of the electrolyzer is inlfuenced by the intermittency of the renewable energy system, resulting in a reduced efficiency. The increased wind speeds may cause difficulties related to the main electricity grid intergration of a high fluctuating energy source.

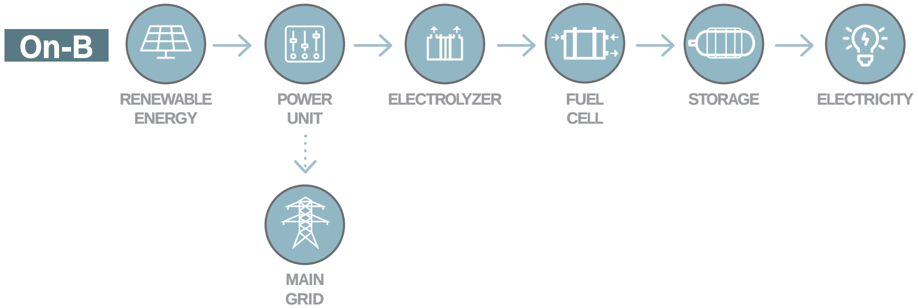


Figure 3.4. Scheme ON-B configuration

Besides the traditional arrangement between off-grid and on-grid, is the distributed energy production through microgrids. The microgrids can perform either autonomously or supporting small grids that are conected to the main electricity grid. Depending on the microgrid characteristics, hydrogen energy systems with storage vessels and fuel cells, can be highly efficient, and even when necessary additional components such as ultracapacitors batteries, and diesel generators can be applied.

3.2 The hydrogen office project

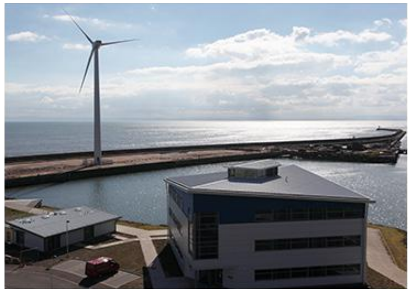


Figure 3.5. The Hydrogen Office, Retrieved November 27, 2017, from http://www.brightgreenhydrogen.org.uk/home/hydrogen-office-project/

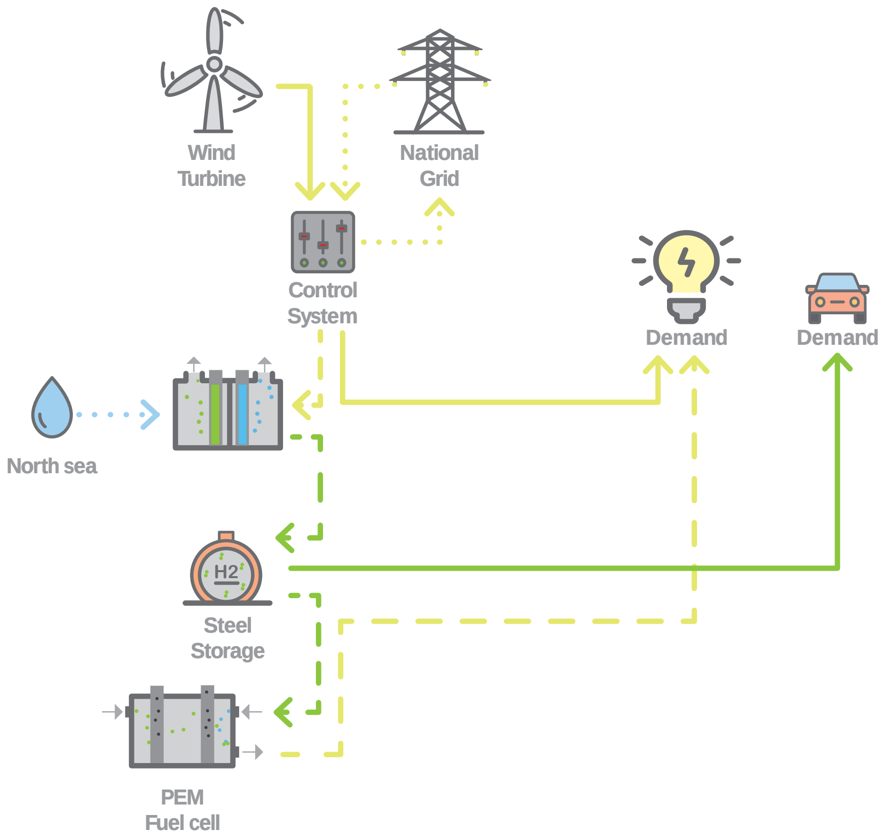


Figure 3.6. The Hydrogen Office, schematic energy diagram

The building is located in Methil, United Kingdom and is powered by renewable energy and hydrogen energy system, developed by Bright green Hydrogen (2013). During the periods where renewable energy cannot meet the demands, hydrogen will be used to make up the difference.
This hydrogen system contains a 750kW wind turbine, it is 55m tall with 23,5m blades. The extracted energy from the wind will be used directly by the office and excess electricity will be delivered to the electrolyser, while the rest of the excess energy is sold to the grid. The electrolyser that is used is a 30kW Alkaline model built by Erre Due. This electrolyser has a potassium hydroxide electrolyte, two electrodes and a diaphram that only allows the reacting ions to pass through and not the gasses. The hydrogen will be purifed at a pressure of 12bar before entering the storage. At this moment the system is currently air cooled and the waste heat is not reused. The hydrogen is stored in a stainless steel tank, this 7500kg tank stores 11kg of hydrogen. Altergy systems has provided the office with a 10kW Proton Exchange Membrane fuel cell. The office also holds a 5kW hydrogen boiler, this supplies heat for a nearby innovation centre.

3.3 The Phi Suea house

Figure 3.7. The Phi Suea House, Retrieved November 27, 2017, from http://www.chiangmaicitylife.com/citylife-articles/a-butterfly-effect-phi-suea-house-project/

The Phi Suea house is located in Chiang Mai developed in 2016, it consists of 4 housing blocks and a several support buildings. Renewable energy is used directly when it is available, while storing additional energy as hydrogen. It is similar to The Hydrogen Office, only instead of a wind turbine Phi Sue House makes use of photovoltaic panels. These are installed on top of the five buildings. Throughout the entire year there is a lot of sun in Chang Mai, with a total average production of the solar panels of 140.233kWh/year. During the day the a part of the excess power is stored in two 2000-Ah lead battery banks. The other part is used to produce hydrogen through the electrolyzer. When it is running at full power it can produce hydrogen at a maximum rate of 2.000L every hour and able to store up to 80.000L. At night the hydrogen is converted back to electricity through a fuel cell. The Phi Sue House makes use of an Anion Exchange Membrame. The daily demand for electricity for the district is approximately 200kWh and the maxium output at full storage is 120kWh, this will be enough to cover the night demand of around 80kWh.

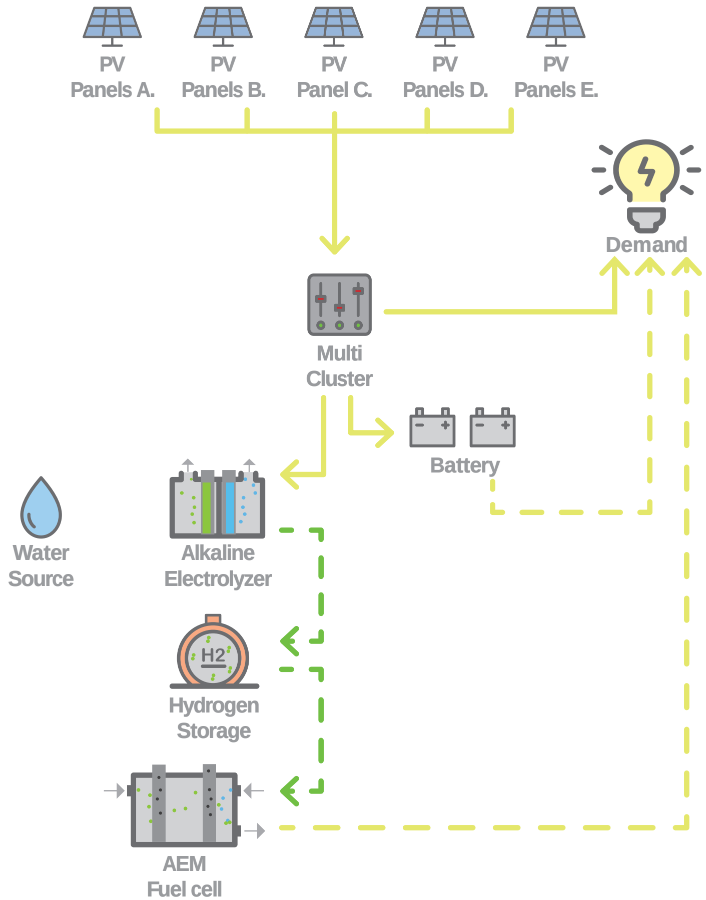


Figure 3.8. The Phi Sue House, schematic energy diagram

3.4 Sir Samuel Griffith Centre

Figure 3.9. Sir Griffith Centre, Retrieved November 27, 2017, from https://app.griffith.edu.au/sciencesimpact/sir_samuel_griffith_centre/

The Griffith Centre is a 6000m² which houses research and teaching activities developed by COX architecture (2015). This newly installed sustainable energy system is based hydrogen production from solar energy. The purpose of this hyrdrogen system is to demonstrate an autonomous energy system, with long term hydrogen storage, running off-grid as much as possible. Similar to The Phi Suea House, the primary energy production are photovoltaic panels, which are installed on the roof and facade. First the solar energy will be charged in a bank of Li-ion batteries (short-term storage). When this is fully charged the excess energy will be used to convert water into hydrogen through Alkaline water electrolysers. The produced hydrogen is stored in a proprietary metal-hydride storage with a total capacity of 135kg, equal to 2,3MWh (long-term storage). When the efficiency of the solar panels is lower than the demands, then then batteries initially provide for the building's energy requirements. If the batteries drops to a certain level, hydrogen will be converted to electricity through the fuel cell (PEM). The building will reconnect to the grid, if both of the storages becomes depleted.

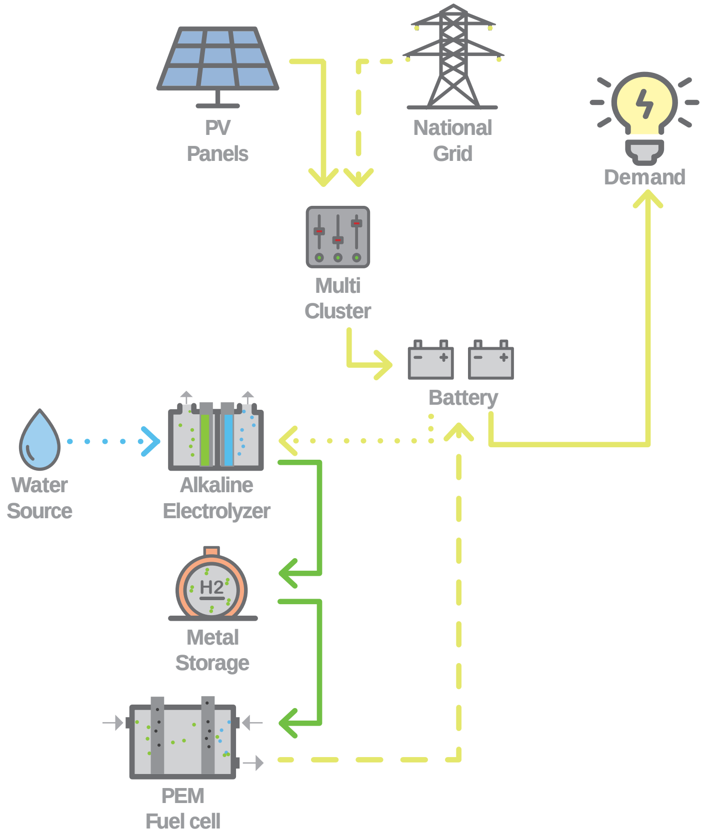


Figure 3.10. Sir Griffith Centre, schematic energy diagram

Chapter 4
Initial activities

4.1 Introduction

In this chapter the project location will be analysed. Defining the surroundings and orientation. Together with Port of Rotterdam the program will be composed with the correlating surface. Depending on the interested third party the route and eventual requirements will be provided.

4.2 Location

The project location is RDM Rotterdam, back in the days it used to be a yard also called Rotterdamsche Droogdok Maatschappij (RDM). An old-fashioned company where pride of craftsmanship was used for the construction and repairs of ships. 100 years ago the yard have built the village Heijplaat. The predominantly lower class workers houses were intended for employees of the yard. In 2004/2005 there were plans to demolish the sheds and buildings on the site in terms of restructuring of Groot Heijplaat area, according to Heijplaat (2018). Later, it was decided not to demolish the buildings on the former site, but to revitalize the historic industrial heritage instead. Port of Rotterdam was the initiator of this plan.
Today this is the spot for innovation for in the port, it offers innovative companies, education and research, see figure 4.1. Here they work together on innovations that contribute to a smart port.
RDM Rotterdam can be accessible by car, public transport or water transport. RDM Rotterdam has three parking areas, P1 is located at the Heijplaatstraat and is intended for the Congress Centre, P2 is located next to Central Warehouse and P3 is behind the Innovation Dock, next to the Scheepsbouwloods. In addition, there are some parking along

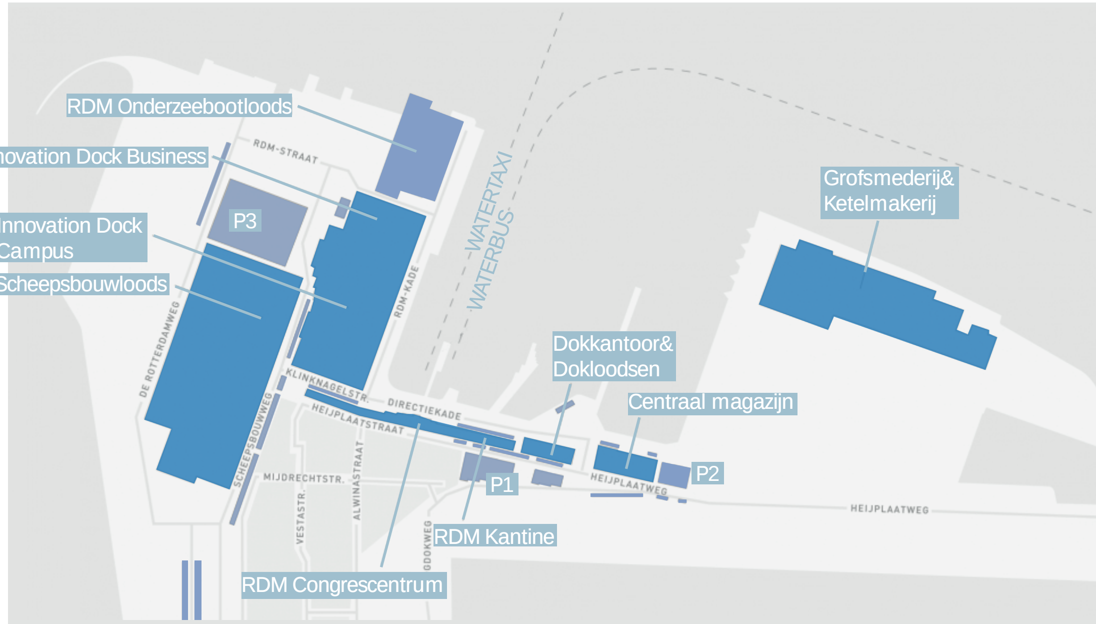


Fig. 4.1., RDM Rotterdam, Functions and surroundings

the Heijplaatstraat, Heijplaatweg, Directiekade and Klinknagelstraat. Parking at the RDM is free of charge. It is also easy accessible by public transport, the RET bus line 68 stops at the Heijplaatsstraat 23. And even accessible by the waterbus and watertaxi. Line 18 of the water bus sails from Erasmusbrug, St. Jobshaven and Katendrecht to RDM. This catamaran sails twice in an hour. RDM can be reached by watertaxi from all the watertaxi locations.

4.3 Program of Requirements

Within the development of the ‘Energy Island’ there are different focus points; promoting renewable energy storage, knowledge, and showcasing new technologies around the use of renewable hydrogen. Additionally, it is about realization of the missing links in the hydrogen chain, especially between renewable energy storage - converting H2 fuel - distribution and bunkering of the shipping industry and possible in time providing concrete H2 bunker needs of customers. In the Port of Rotterdam there is an ongoing exploration taken place together with Nedcargo - Heineken. In addition to this collaboration, during the process other parties also want to affiliate in this project.
With this development, besides allowing to bunker H2 fuel, but also bring in more parties in motion to achieve sustainable (transport) solutions, making green hydrogen as a fuel for shipping commercially more attractive; and sustainability boost by sharing knowledge on alternative energy forms and applications as well as business users to consumers.

There is a small hydrogen lab located in the RDM campus. In this lab only small scale test can be conducted, due the lack of the permit to operate on large scale. Partly caused by the higher risk of the other activities in the campus and by the occupation of other students that are not involved with the hydrogen research. In context of promoting and sharing knowledge of hydrogen a choice have been made to collaborate with the RDM campus to realize a larger lab on the Island. This will give the researchers more possibilities. Besides showcasing the energy system of the Island itself, where the target audience is for the most part business users, the goals is also to inspire the public. Therefore in the large variant an exposition/information center is offered the public. Here different research results or developments will be on display. With the focus points and goals a first range of the program of requirements is made by the Port of Rotterdam. This is a first concept, the functions and surfaces still can be changed during the process.

Activities on the Island functions

Locatie:		*minimale – maximale variant*		
A	Locatie Dokhaven (ponton)	Minimaal (Aqua Dock): 300m2	Tussenvariant: ca. 450m2	Maximaal: 600m2
Power-to-X:				
B	Opwekking renewable energy *(zon / wind)*	Wind/zonne-energie levering aan het eiland middels 'stekker'	Wind/zonne-energie opwekken in de nabijheid van het eiland	Wind/zonne-energie opwekken op het eiland
C	Omzetting *(van elektriciteit naar waterstof via elektrolyse)*	Elders	nabijheid van het eiland	op het eiland
D	Tussenopslag	Elders	capaciteit gelijk aan de vraag	2x de capaciteit van de vraag
E	Omzetting / conversie	Elders	gecontaineriseerd	hydraulische tegendruk
Bunkeren:				
F	Bunkeren	kleine hoeveelheden middels flessenpakket	grotere hoeveelheden via containers of tankopslag	
G	Te bunkeren schip	Pilot persoonsvervoer kleine afstand	Binnenvaartschip middelgrote afstand	Binnenvaartschip grote afstand
Nevenactiviteiten:				
H	Onderzoekscentrum Living Lab	opwekking tot omzetting **power-to-H2** conceptuele weergave proces		opwekking tot omzetting **power-to-H2** laboratorium schaal op het ponton
I	Informatiecentrum	Kleinschalig: *bijvoorbeeld rondleidingen of beperkte openingstijden*	Middel groot: *bijvoorbeeld rondleidingen en tentoonstellingen*	Groot: *rondleidingen, tentoonstellingen, koppeling kennisinstellingen, vaste programmering, …*

Table. 4.1., Variants of Island of with different activities

With this list of different variant of the Island a bubble diagrams is created to graphically illustrate the program and create a logical space planning and organization of the largest variant. In this first bubble diagram a separation is made from the public, however there are still shared space between private and public. The employees from the bunker station and lab can reach their spaces though the public squares. By placing the functions in a way that they are somehow connected will create a dynamic and coherent organization. In this organization there is chosen for one large ponton, with the bunker function on the right side. The ponton can be reached by a pedestrian bridge from the RDM.

4.4 Inland ship demands

This showcasing Island is intended for one inland ship. It is important to gain reliable numbers for the demands of the requirements. This is due to the fact that the ship consumes most of the hydrogen. The amount of hydrogen the ship consumes defines which energy components and storage is needed for the Island, this is linked with the amount of surface is needed for the installation. The party NedCargo-Heineken will replace their current ship De Gouwenaar, the trip of this ship is from Alphen aan de Rijn to Rotterdam, fully loaded away and empty containers back.
Ballard have been asked to make a data-analysis. Ballard's aim is to use

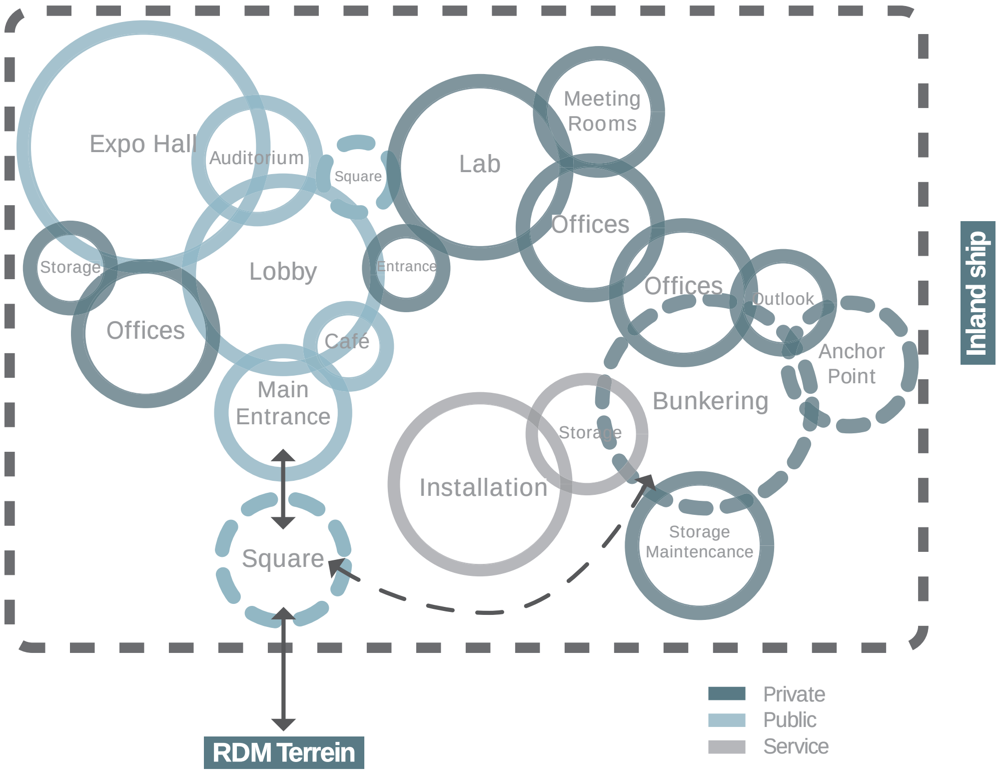


Table. 4.2., First concept list of function with the corresponding surfaces

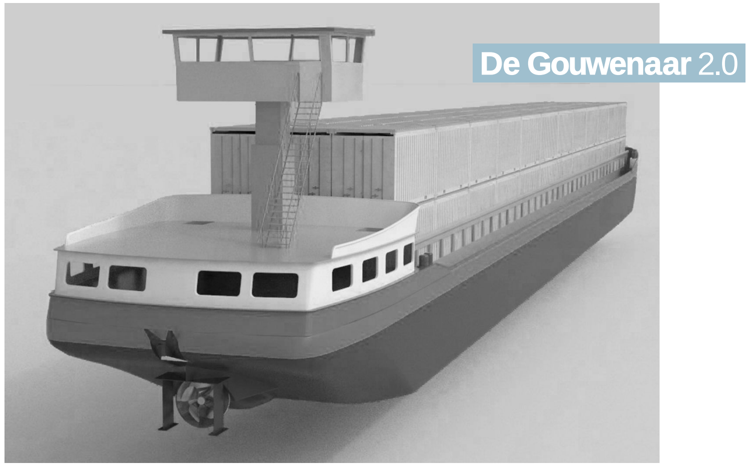


Figure 4.2. De Gouwenaar 2.0, Retrieved April 9, 2018, from hhttp://www. maritiemnederland.com/achtergrond/bierboot-op-waterstof/item2201

their extensive fuel cell and systems know-how to profitably deliver innovative clean energy solutions to their customers (Ballard, 2018). The modeling of the optimal use of the fuel cell and battery for De Gouwenaar is based on their own model. The fuel cell will supply energy to the battery when the battery is op to 60% full and stops at 85%. Using the battery as long as possible is operationally the best choice. A minimum load of the battery of 20%, while it has been indicated that occasionally falling below this level will not shorten the lifetime of the battery. Ballard has calculated a number of scenarios, but comes up with a 420kg hydrogen requirement for the return trip Alphen aan de Rijn - Rotterdam, with an optimal distribution of 600kW for the fuel cell and 200kW battery. This is done based on current fuel cells and batteries and is the maximum amount based on the expected end-of-life of the battery and fuel cell. Currently they are working on new developments, which will be on the market in 2019 and will therefore be applied in De Gouwenaar, the units will lower compared to the current analysis.

Because of the efficiency curve (better with fuel cell) and the costs of refurbishment (only replacing membrane with fuel cell and entire unit with battery) Ballard advises to apply a smaller battery and larger fuel cell, also the size of the fuel cell is much smaller than the battery. The life expectancy of the current fuel cell is now at least 15.000 hours, around 10 years for the Gouwenaar case and the expectation is that this will be in the direction of 20.000 hours (Oben Uluc, Ballard, 2018).

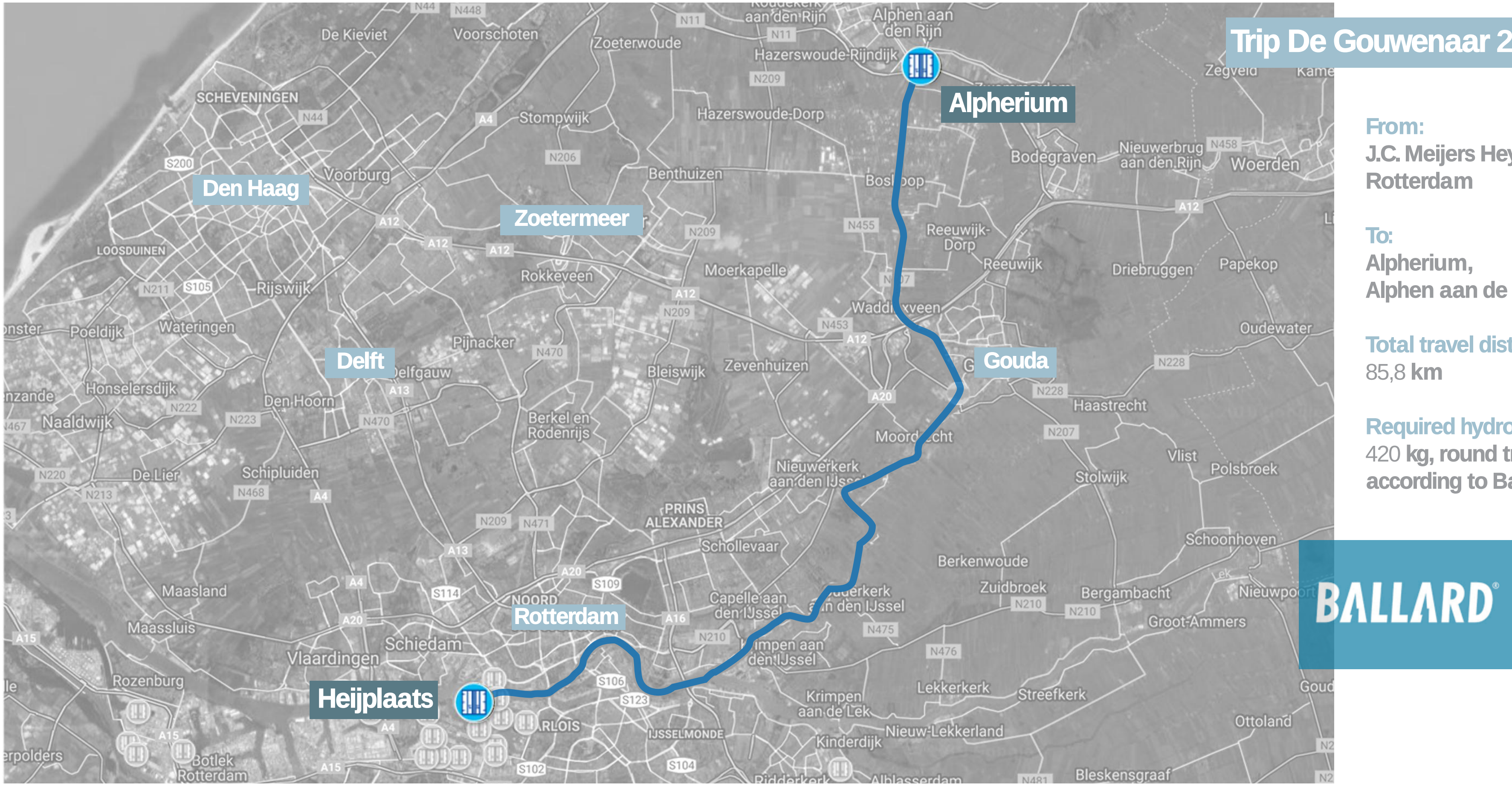


Figure 4.3. De Gouwenaar 2.0 route from Rotterdam to Alpherium

4.5 Energy concept

The first energy concept for the Island is based on the case studies and input from The Port of Rotterdam. Electricity will be acquired through solar panels through the main electricity grid. This is necessary mainly due to the high hydrogen requirement of the ship and there is not enough space to provide it with renewable energy alone. The power generated through the renewable energy sources will be used directly by the building, excess energy will be used to power the PEM electrolyzer. Inbetween a battery storage is placed to assimilate the peaks from the renewable energy sources. By doing this the PEM electrolyzer will have a constant power input, this way it will be most efficienct and not shorten the lifespan. The required water will be provided through a pump from the Nieuwe Maas. This water will be filtered and de-ionized. The produced hydrogen will be compressed and stored in a middle pressure storage and from this storage antoher compressor will be applied to the high pressure storage. When the ship is ready to bunker the hydrogen from the high pressure wil go through a dispenser into the ship.

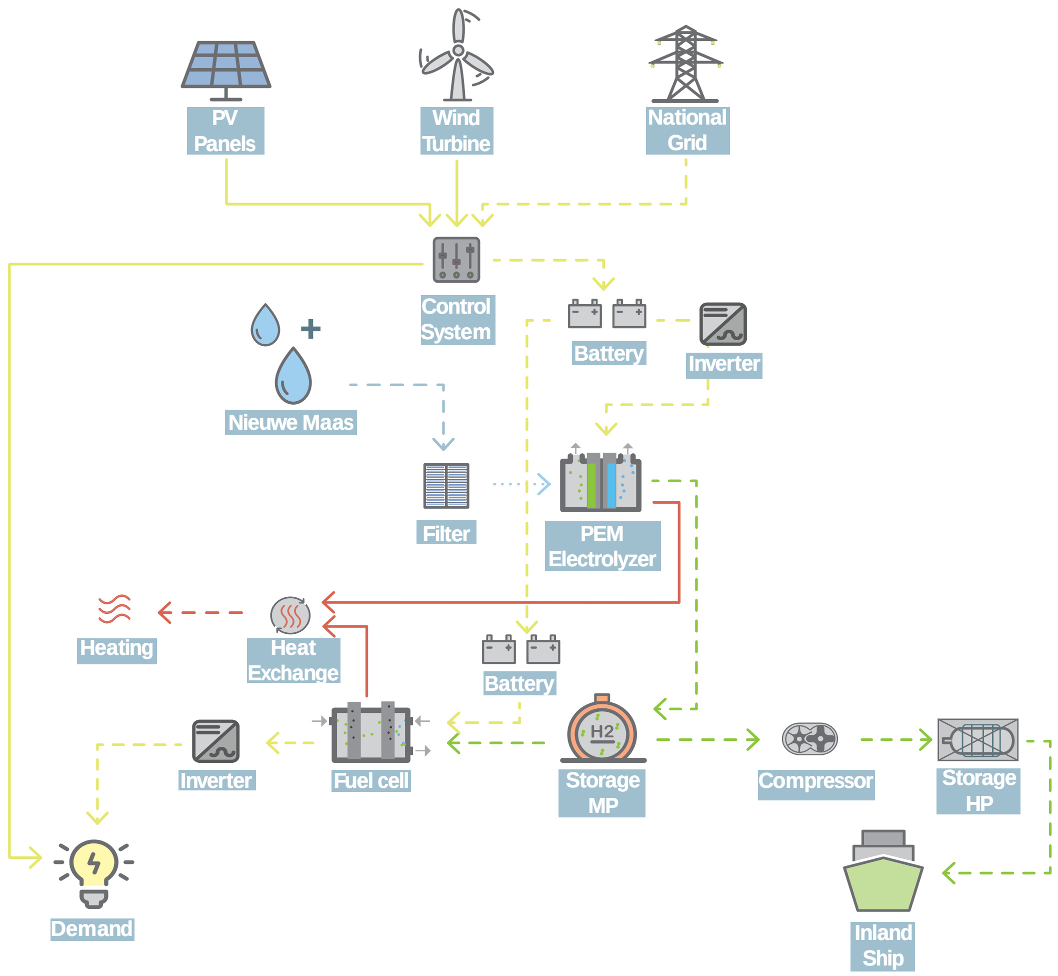


Figure 4.4. Energy concept for the Island

Chapter 5
Design Process

5.1 Introduction

The process of design will be described step by step in this chapter. From sketches to the final chosen design. The pros and cons of each concept will be shown. Input from different experts and decision making will be explained, before going to the next step. In this chapter it will become clear why the final concept is chosen

5.2 First phase (sketches)

INPUT

After the first concept of the program of requirements, the first sketches are made. The first input that is given by PoR is that if the government is going to grant a permit. Interventions should be made to the primary risk, the hydrogen storage of the Island with the worst case scenario an explosion of the storage. If an explosion occurs then there are three effects that should be minimized, those are the overpressure and the primary fragments and the secondary fragments

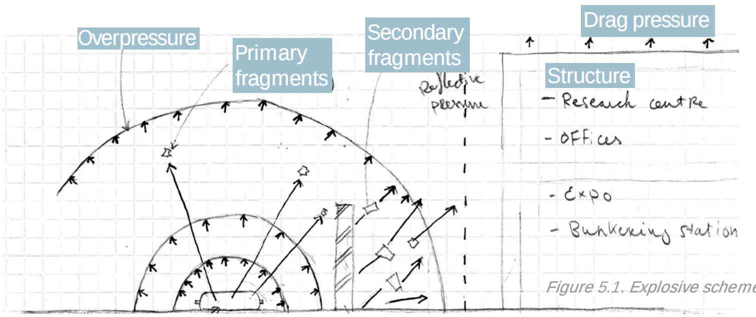
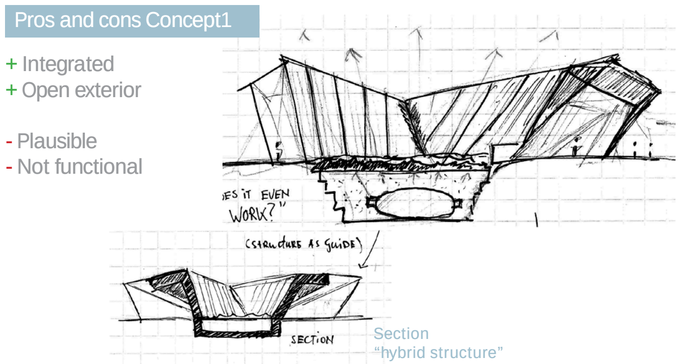


Figure 5.1. Explosive scheme sketch

of the vessel. Therefore, the sketches were made to orientate what the possible options are in context of how to contain or guide the explosion to ensure the safety of the visitors and employees. This should be integrated in the architecture, safety and the structure have to support each other.

PROPOSALS

Concept 1:
In this concept the storage is isolated and surrounded by water, the water will serve as first layer to soften the impact of the blast. The heavy diagonal structure is designed in a way that the blast will not directly hit the facade, but guide the blast upwards. On the inside a heavy structure and on the exterior a open facade.



Concept 2:

The storage is semi-isolated, on the sides it is surrounded by heavy concrete wall, acting as a shield with an open roof where the blast can escape. The functions are around the heavy wall, from the exterior it have a image of an light and open building.

Pros and cons Concept2

+ Semi integrated
+ Open exterior

- Not functional
- Dull form

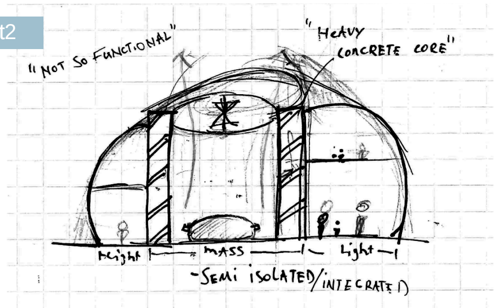


Figure 5.3 Concept 2 sketch

Concept 3:

This concept is a combination of concept 1 and 2. The storage in located in the middle of the structure. The heavy uniform structure serves as a shield and guide for the blast. The functions are inside these heavy walls.

Pros and cons Concept3

+ Integrated
+ Uniform

- Not functional
- Heavy

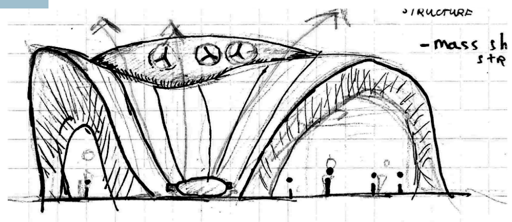


Figure 5.4 Concept 3 sketch

Concept 4:

The storage is semi-isolated and located on the side of the structure. The walls direct to the storage should be strong enough to protect the structure. This allows a light structure for the public building. Each circular form represents a different function.

Pros and cons Concept4

+ Semi integrated
+ Free exterior

- Not functional
- Dull form

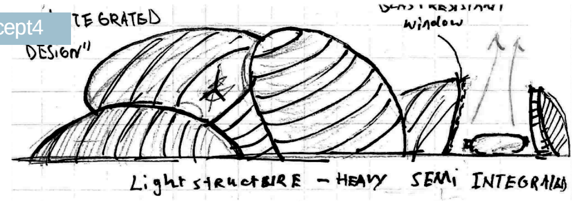


Figure 5.5 Concept 4 sketch

Concept 5:

The storage is seperated from the building, which allows the building to be freely design. The walls of the storage should protect the building, however when the distance of the storage is higher the walls can be slimmer

Pros and cons Concept5

+ Functional
+ Free exterior

- Not integrated
- Dull form

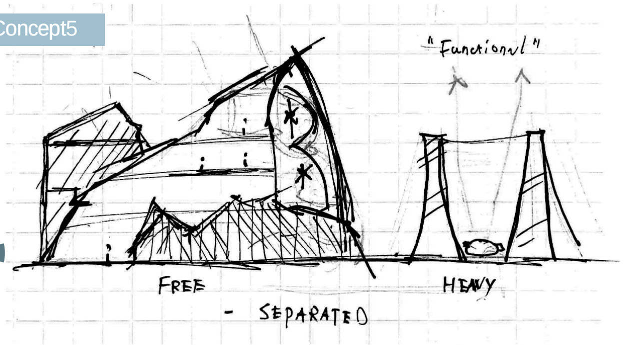


Figure 5.6 Concept 5 sketch

Concept 6:

The storage is totally isolated and located in the center of the structure. The functions are located on the on the side of the heavy “bunker”. If a calamity occurs with the storage the bunker should contain the blast, a bit similar to the principle of a nuclear reactor.

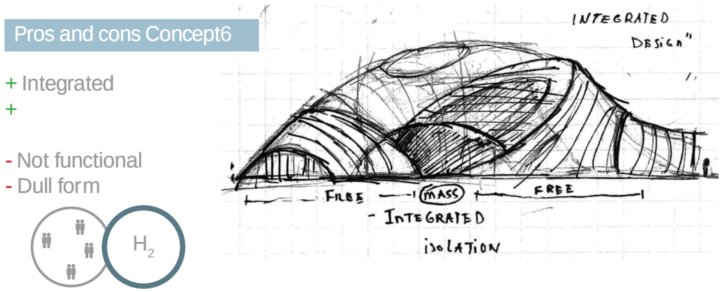


Figure 5.7. Concept 6 sketch

Concept 7:

The storage divided into smaller storages in placed in the to cylindrical forms. If a calamity occurs to one of the storage, the blast would be probably smaller and can easier be controlled. These also serve as the construction of the building.

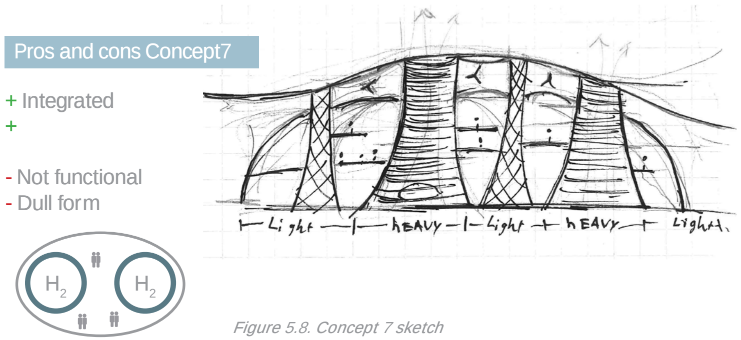


Figure 5.8. Concept 7 sketch

EVALUATION (CEES BOON)

With these sketches and the first program of requirements were presented to Cees Boon, Sector coordinator Harbormaster Policy Dept, port security development within Port of Rotterdam. This Island will be the first hydrogen bunker station for ships and meeting up with Cees Boon will give his initial thoughts of this bunker station and what the possible obstacles and challenges will be to obtain a permit. In the sketches the main approach was to contain or guide a possible explosion. This approach was not correct, if something happens to the hydrogen storage, the main risk will be heat radiation. Therefore internal distances should be taken into account. This may possible be reduced if the risk component is compartmentalized with a fire proof wall. However, Cees is not convinced that the safety is ensured of the public function, the distance between them is too small. The energy components should be functional, for example in some of the sketches the storage in located in the center of the structure and the hydrogen have to travel across the structure to reach the ship. If the energy system is more functional it can reduce the risk. Additional points are the exact energy requirements and the method of bunkering.

Summary

At the moment Cees Boon is not convinced that the safety for the public can be ensured. He assumes that the “large” amount of hydrogen will be too close to the public and the minimal distance will be exceeded. An option that he has given is to minimize to use of hydrogen and only operate on small-scale. However, this is more avoiding the problem rather than accepting a challenge, because the main objective is still a hydrogen bunker station for an inland ship.

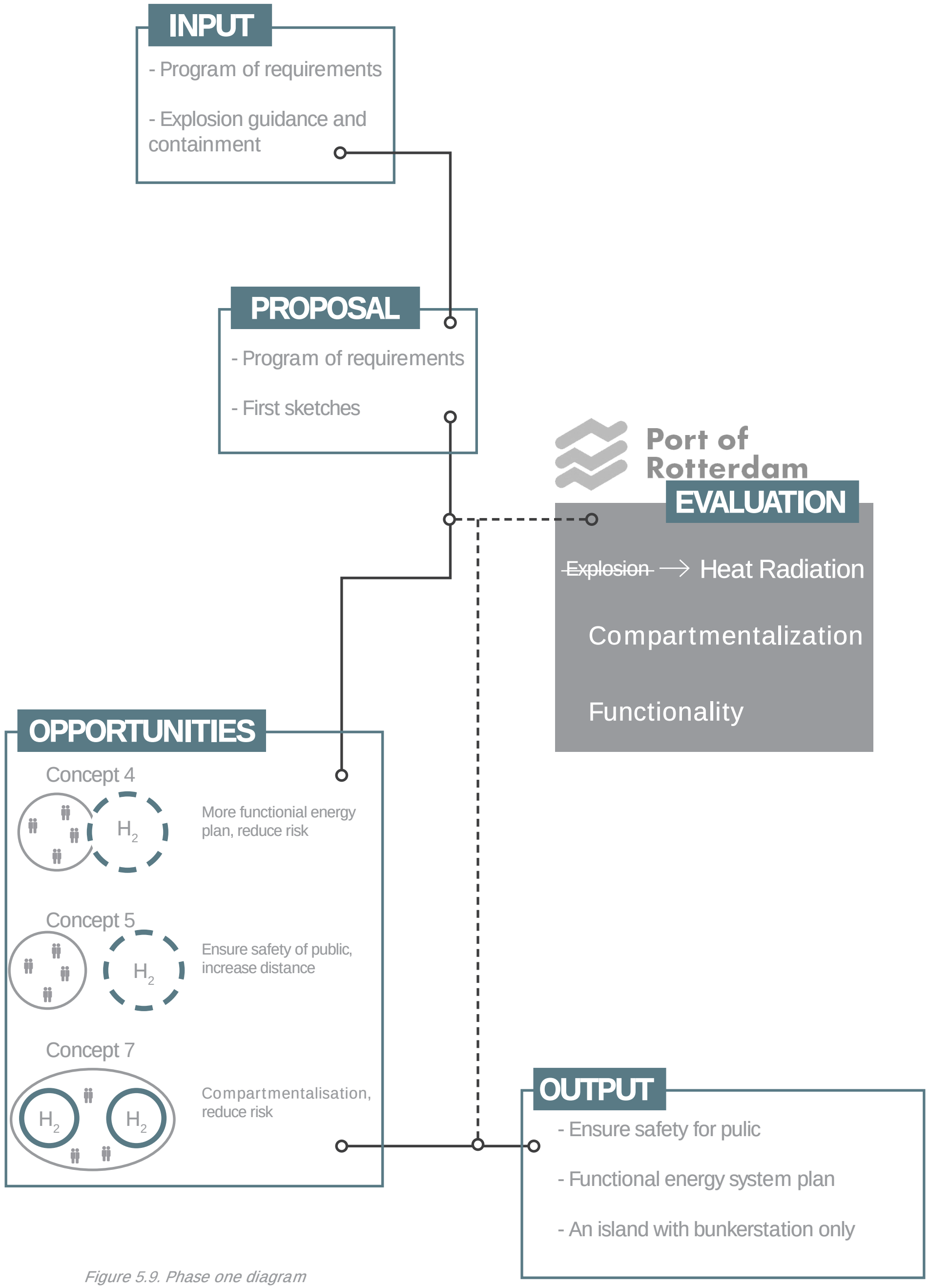


Figure 5.9. Phase one diagram

5.3 Second phase (Droplet & Wave)

INPUT

The input for the second phase is the start of the output of the first phase. From the previous evaluation it was not convinced that it will be safe for the public. However, the main objective is to create a bunkerstation for an inland ship. Therefore the first bunkerstation that will be proposed is one without public functions (smaller variant). In the second phase, the key opportunities from the evaluation of the first phase will be implemented.

PROPOSALS

DROPLET:
The first proposal is a variant with bunker station only. This include the following functions, office, electrolyzer, storage MP, compressor, storage HP and dispenser. The starting point for the droplet is sketch concept 7. The energy components will be separated from each other, with the idea is if something happens to a component it will not affect the other components. The components are also placed in a logical sequence

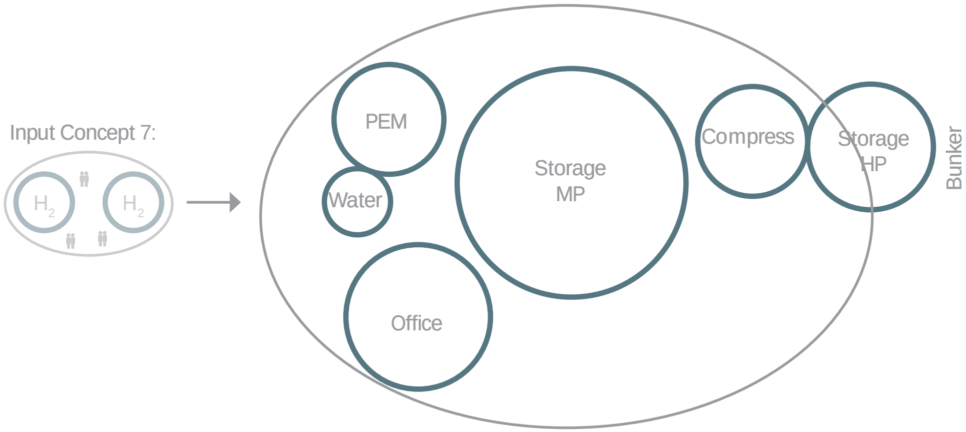


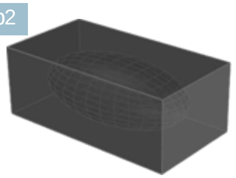
Figure 5.10. Schematic energy system concept 7

The idea behind the structure is to make something compact and does not have the image of hydrogen production, but having a image of something strong and rigid. The structural approach that is chosen is kangaroo minimal surface to achieve an efficient structure. Below the steps are briefly summarized.

Step1

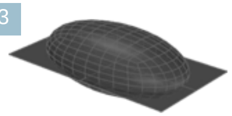
As starting point a box which is large enough to place the storage MP in the middle where the most space.

Step2



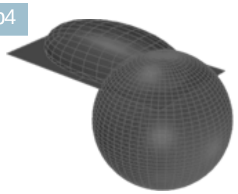
With grasshopper and kangaroo a minimal surface is made from the box. The script is shown on the right.

Step3



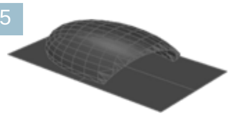
The minimal surface is cut from the with a plane. Which also serves as the ground level of the Island.

Step4



The bunkering of the ship should be open. This opening is made by cutting with a sphere. The opening is larger on the south side where
maintenance or parts delivery will arrive

Step5



Final form with the opening on the bunker side.

Figure 5.11. Steps of form finding of the Droplet

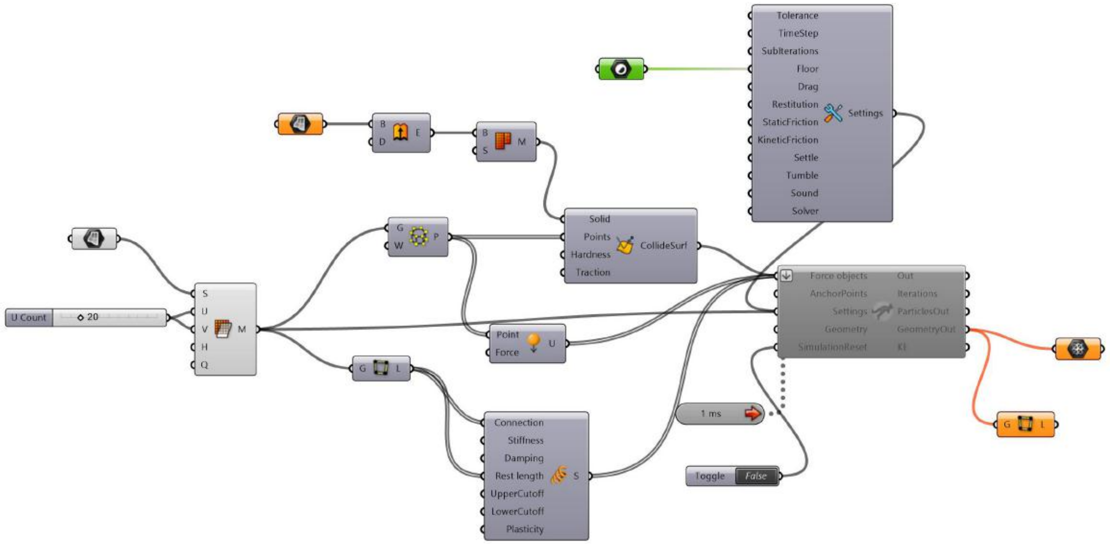
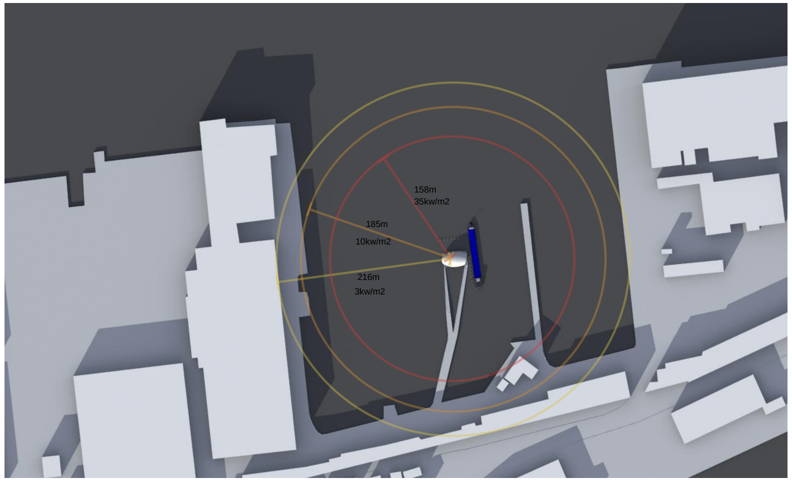


Figure 5.12. Grasshopper script of the Droplet

The Island is connected to an existing pier with a bridge, this bridge is create a bit more distance between the Island and the surrounding building on the south. In chapter 6 the effect distances of fire department of Amsterdam are mentioned. In this image it is shown that there will be no damage to the surrounding buildings if a crack occurs of 100mm with the applied 350 bar storage. The assumption can be made that the distance will be a bit smaller because the storage is isolated.

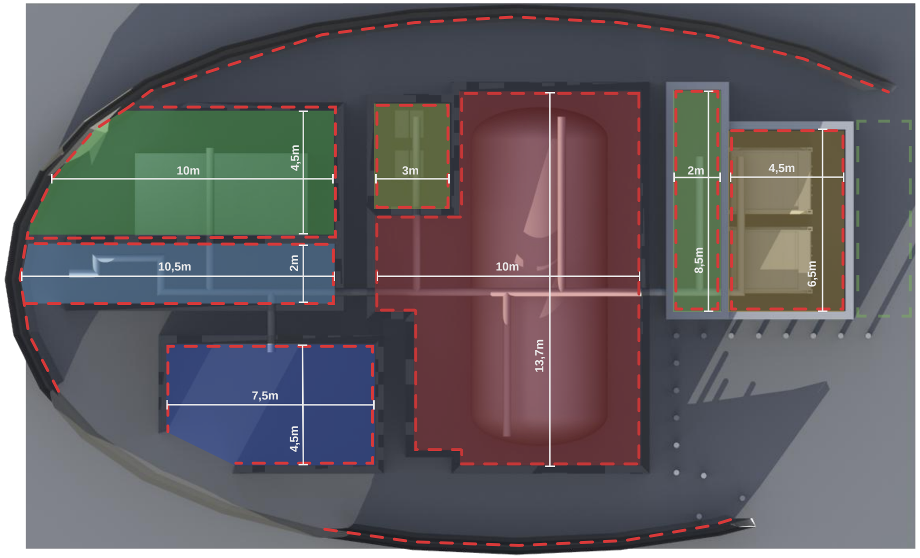


Legenda

132m, 35kw/m² 157m, 10kw/m² 180m, 2kw/m²

Figure 5.13. Droplet effect distances according to fire department Amsterdam

The form is shaped with the largest space in the centre of the building, this is where is storage MP is located. On the left is the start of the energy system. This is where the electrolyser and the water pump is placed and also the air intake. These are the first components to produce hydrogen. The produced hydrogen will travel to the right to the storage MP. From here is will be compressed and stored and ready to bunker when the ship arrives. All the components are separated from each other by a travel space. If calamity happens in one space it will have to go through two fire barriers until reaching another component. This proposal should have the image that the dangerous goods are contained. That is why the components are not in direct contact with the facade. The facade will be relatively thick to show and have good fire resistance properties. The office is located next to the exit, if fire breaks out the can escape quickly. Additionally because of the separation there are always two escape routes. There are two different entrances only for the employees and one for access for emergency services. On the entrance for vehicles safety posts are placed, to absorb the impact before hitting any critical components. The total surface of this proposal is 540m2.



Legenda

PEM electrolyzer
Water buffer
Office
Battery bank
MP storage
Compressor
HP storage

Figure 5.14. Droplet energy components plan

As mentioned before the energy components are placed in a logical way, the same applies for the air system. The air intake in on left side. Here there are two air intakes one for the electrolyser and the other intake for ventilation of the Island. The air ducts is running from the left through all the energy components to the right. The distance between intake and exhaust is maximized for the reason that the polluted air will not be blown back in to the building. In the image below there are extra air units placed in the storage. On the side there is a stairs that goes up, this is where employees easily can check the energy components from above and air handling units.

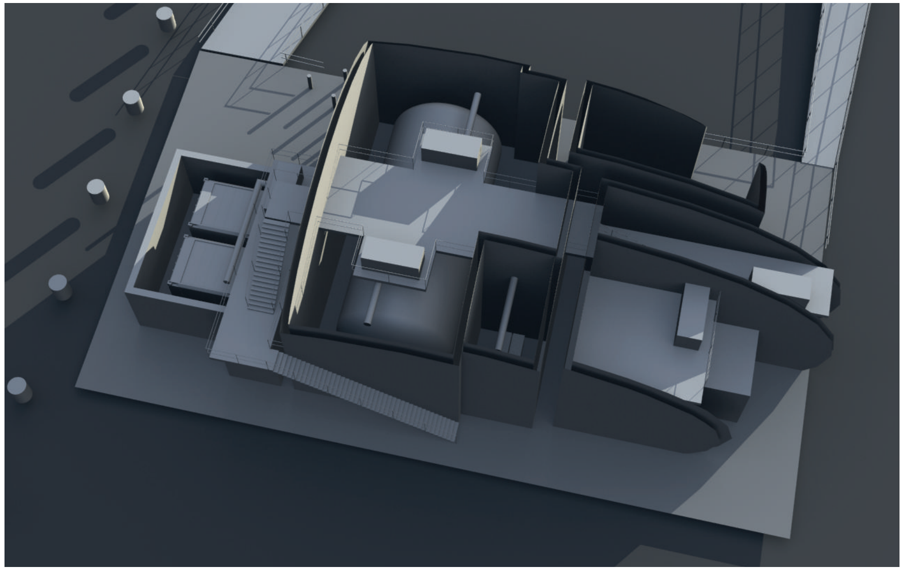


Figure 5.15. Persepective view of the Droplet energy system

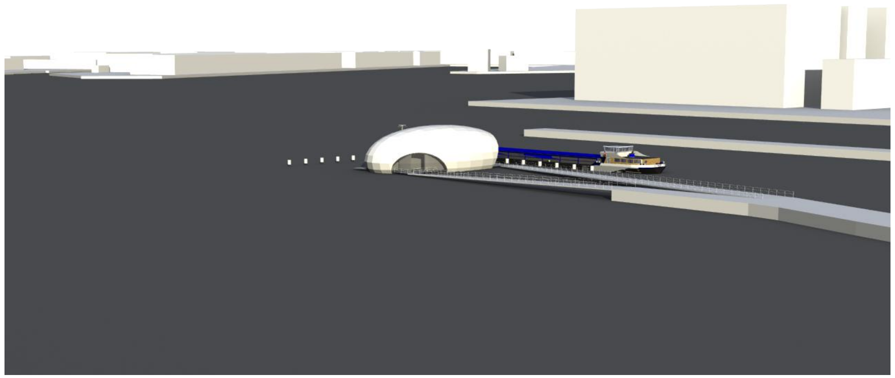


Figure 5.16. Bird eye view of the Droplet

WAVE:

The second proposal is a variant with bunkerstation and research centre. With the following functions, office, research center electrolyser, storage MP, compressor, storage HP and dispenser, The starting point for the wave is sketch concept 4, the hydrogen storage will separated from the people, in this proposal these are researchers and employees (experts). In this proposal the idea is to show a bit more of what happens in this Island. The Droplet is more modest and the Wave will be more exuberant to impress the surrounding public more.

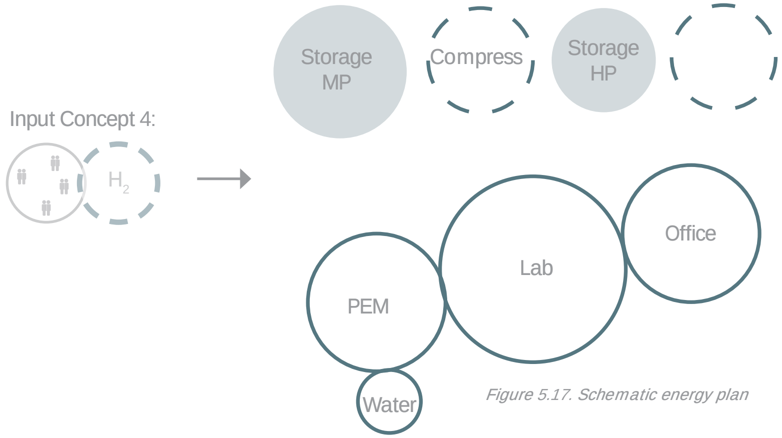
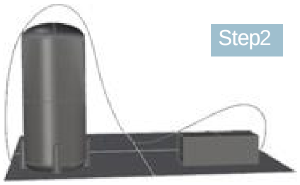


Figure 5.17. Schematic energy plan

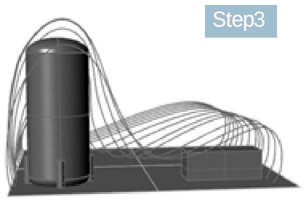
The idea behind the structure is to make something exciting and show a part of the hydrogen production. To partly show what is happening on the Island the decision is made to let the structure flow with the energy components. The storage MP is placed vertically to have more space on the floor plan and create a height difference. The structure will follow the height of the storage MP and the electrolyzer. The principal for this structure is caternary line following the components with three anchor points creating a dubble curve line. The curves are much higher at the components, the curves becomes lower when the height is not needed and at the bunkerstation it is partly open. Below the steps are briefly summarized.

Similar to the droplet the Wave is also connected to the existing pier with a bridge. The effect distance according to firedepartment Amsterdam is likely higher because it is in direct contact with the outside. Nonetheless it is still within the distances.

As the starting point placing the to largest components, with the storage vertically



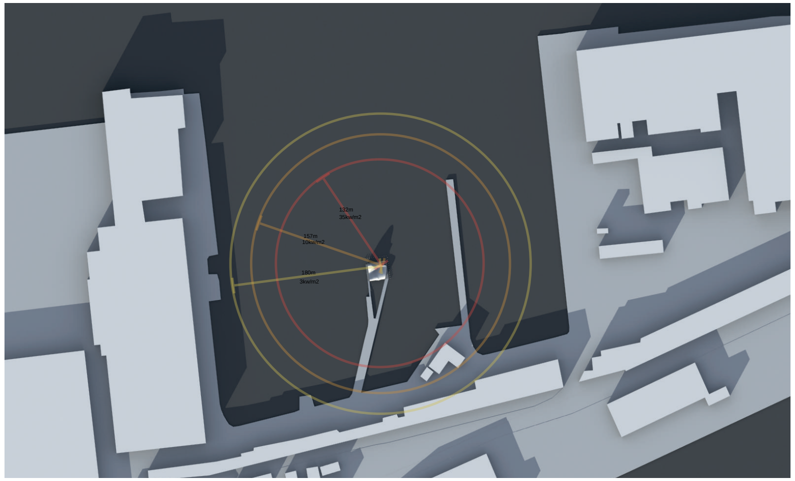
Drawing a curve over the components



Drawing more curves that becomes smaller when the height is not needed.

Final form with closed structure and the seperation of the electrolyzer, office and lab with the storage that is semi open

Figure 5.18. Formfinding steps of the wave

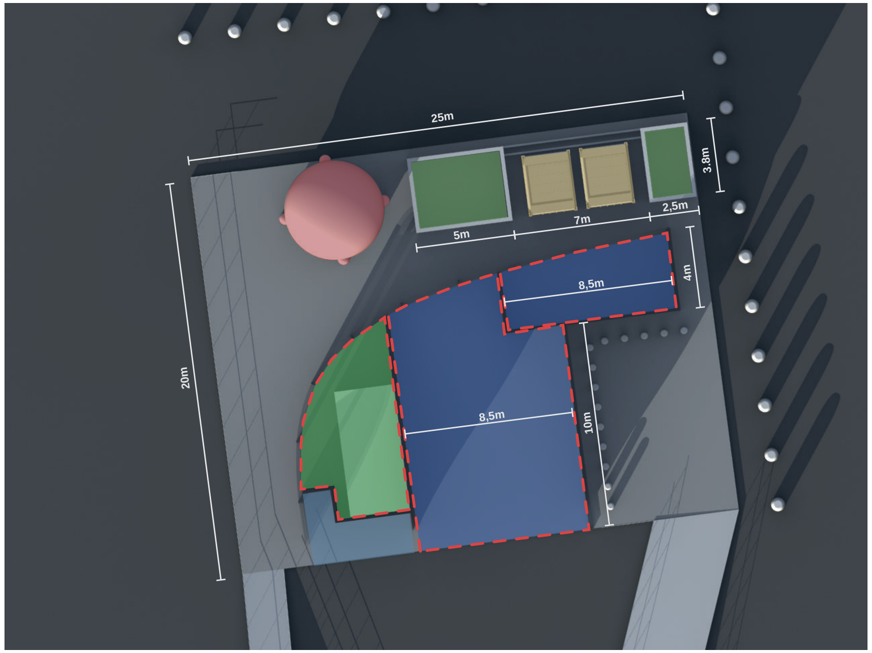


Legenda

132m, 35kw/m² | 157m, 10kw/m² | 180m, 2kw/m²

Figure 5.19. Wave effect distances according to fire department Amsterdam

Mentioned earlier the form is shaped by following the components. The electrolyser is situated on the left end of the building, to feed the electrolyzer with on the south side the waterpump and filter and on the west air intake. The produced hydrogen will travel through the open space to the vertically storage MP. From here the hydrogen will be compressed and stored in high pressure of (350bar) and when the ship arrives it is ready to be bunkered. The lab and office is situated on the south side close to the exit. The elctrolyser, office and lab are protected by a fire-resistant wall, this is to protect the employees if something happens to the storage. There are posts placed in the open space space where maintenance and emergency services arrives, to deprive the chance for impact on the risk components.



Legenda

PEM electrolyzer
Water buffer
Office
Battery bank
MP storage
Compressor
HP storage

Figure 5.20. Wave energy components plan

The ventilation system of the Wave is different than the of the Droplet. The droplet was entirely closed, therefore the ventilation is full mechanical. The wave is partly open and takes advantage of the orientation and wind direction. Because the structure following the components the opening on the left side a lot larger than the side of the bunker system. The fire-resisting wall reinforces this principle creating a venturi effect. Through the narrowed down structure is will create increased wind speed, this will ensure that the structure is well ventilated and prevents hydrogen accumulation. The ventilation of the lab and electrolyser are mechanical, from the side with electrolyser will be blow in and it will be blown off in the open space.

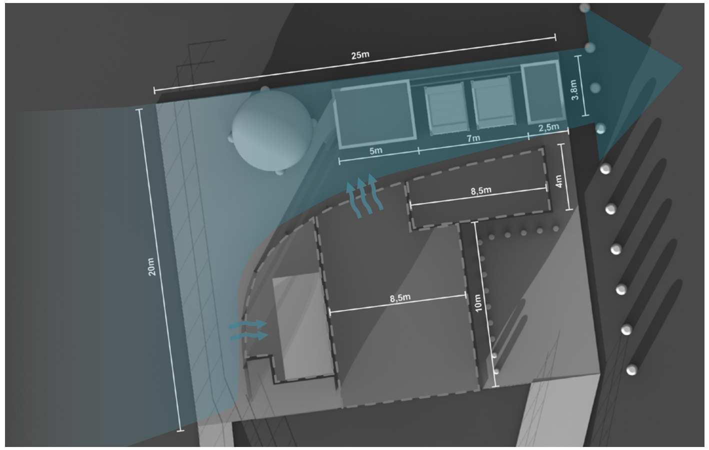


Figure 5.21. Wave energy venturi effect principal

EVALUATION (INTERN+SIEMENS)

With the opportunities from the sketches and together with the evaluation with Cees Boon, two proposals were made, the Droplet and Wave. These are presented to Randolf Weterings (PoR), Maaike Dalhuizen (PoR) and Rogier van der Groep (Siemens). Purpose of this evaluation is to see what is important to the community (public influence) and technical functionality. The PoR wants to show how the hydrogen works to the public and the droplet is the opposite. The wave fits the purpose of the showcase a bit more. It has a more exciting structure and directly show some of the energy components. However, the downsides are that the structure is not realistic to carry out for PoR and the energy components are in direct contact with the outside. The two proposals does not have an exposition or other public functions and it is for PoR important to create public awareness of sustainable solutions.
For the technical functionality the Droplet's energy system plan is better organized. The components are placed in a logical sequence and as close as possible to each other creating the shortest pipes possible.
The wave is not placed next to each other making the pipe from the electrolyser to the storage MP unnecessary longer. The both downsides of the proposals are that the pipes are running through the travel spaces which increases the risk of damage. The maintenance for both of the proposals are not well thought out. The have enough space for small maintenance and check-ups, but almost no space for replacement of the (sub-)systems. A practical point of the Droplet is that it can be checked from above and the air handling units can easily be reached.

Summary

To get a better picture of the evaluation, the evaluation is divided into the criteria; structure, maintenance, functionality, public influence and safety. Below an overview is shown of the strengths and weaknesses.

DROPLET

	STRENGTHS	WEAKNESSES
Structure	*- Realistic structure that can be realized by PoR*	*- A bit dull design with out showing any functions*
Social		*- The public can not see what is happening* *- On the Island there are no public functions*
Safety	*- Compartments*	*- The pipes are running through the travel space*
Functionality	*- Logical placement of the system components*	
Maintenance	*- Checkups can be done from above*	*- No space for replacement of (sub-) systems*

WAVE

	STRENGTHS	WEAKNESSES
Structure	*- Interesting structure*	*- Not very representing hydogen production*
Social	*- The public can see a bit what is happening*	*- On the Island there are no public functions*
Safety		*- The pipes are running through the travel space*
Functionality	*- Open ventilation*	*- Semi logical placement of the system components*
Maintenance		*- No check ups from above* *- Almost no space for replacement of (sub-) systems*

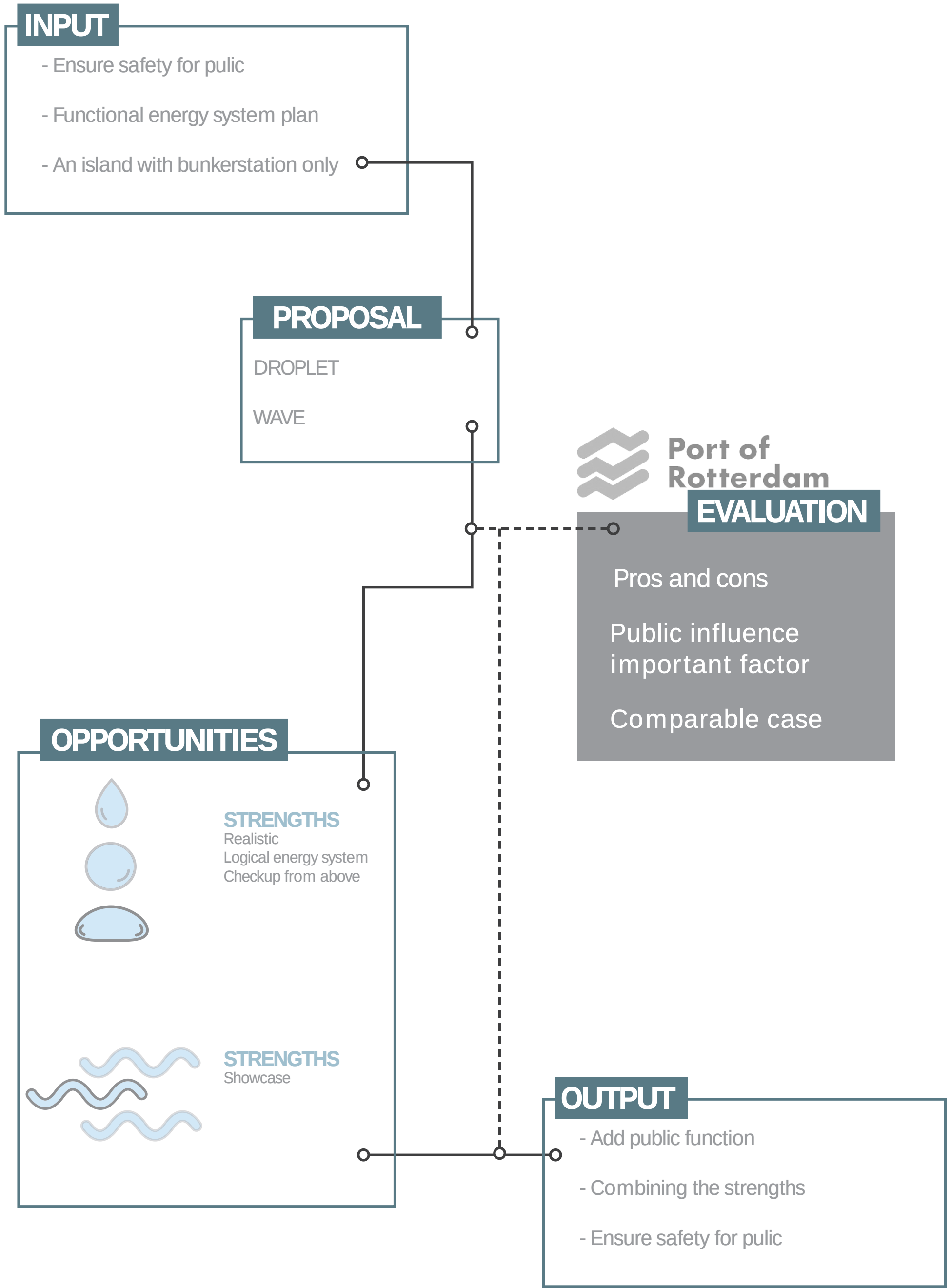


Figure 5.23. Phase two diagram

5.4 Third phase (Split)

INPUT

The input for the third phase is to make a proposal that combines the strengths of the first two proposals (Droplet and Wave) and learn from their weaknesses. For The PoR the public influence is an important factor and it there the Island should have those public functions and showcasing what is happening. However, like mentioned earlier safety must be ensured. To obtain more knowledge how this is done, a comparable case of a hydrogen fuel station will be analysed.

PROPOSALS

COMPARABLE CASE:

A.P. Harris et al. (2014) have made a benchmarking process of result and analysis NFPA2. The NFPA2 have the most influential impact on the lot line perimeter size and s associated safety separation distances required by the by the existing codes and standards.

A.P. Harris et al. (2014) stated that separation distances presented a major challenge to place hydrogen components in a retail fueling setting. Most of the progress up to date has been a private/public joint effort to change the hydrogen-specific code development process from an expert opinion-based system, to a system where scientific data provides the basis for the code requirements; this science basis includes quantitative evaluation of hydrogen releases and integration of this data into a risk-informed approach. This method has resulted in scientifically-defensible safety requirements including the separation distances. Therefore this benchmarking effort focuses on the impact of the change from expert opinion-based to science-based separation distances.
The definite distances for placing hydrogen components next to a retail store are difficult to determine. The safety distances for hydrogen gaseous systems are based on the size of the line connected to the supply system and the pressure. A fire resistant wall can be used for mitigation, 120min fire rated structure that disrupts the line of sight of the system. The safety distances (air-intake and opening - grey, classified

electrical - red). The reference station below has a 100kg per day capacity with a 3 bank cascade fuelling system with a tube trailer supply, compressor and other controls equipment located in the fire protected area, surround by vehicle protection posts. This station is around 511m2 of space with at least one side no shorter than 21 meters in length. There is allowance to overlap the separation distances for buildings and ventilation intakes with the physical building, as the HVAC intake and building access doors may not be on the side of the building closest to the hydrogen components.
It is important to point out that actual siting of hydrogen stations can be a flexible process with local officials. In general, negotiation of system permitting occurs through an iterative process and the zoning of adjacent properties.

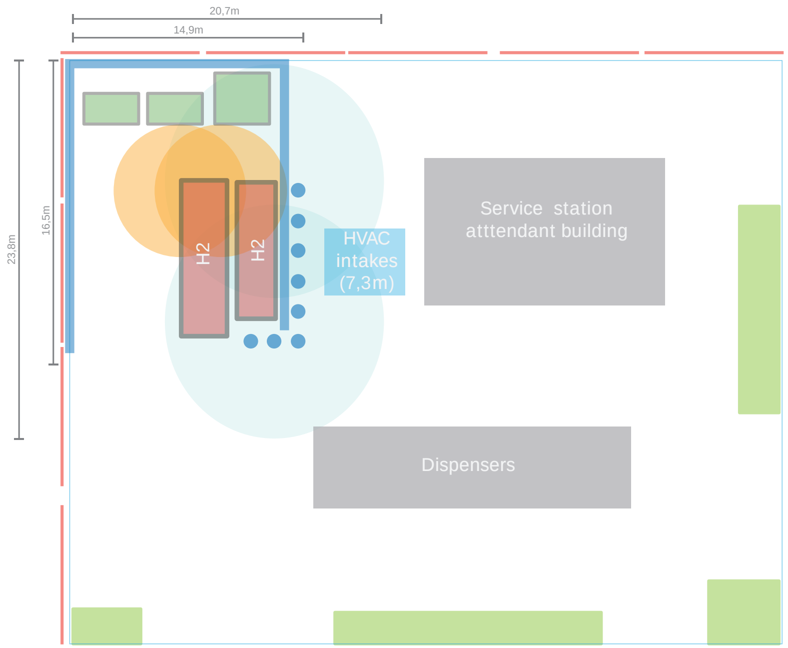


Figure 5.24. Layout hydrogen fuel station for cars according to A.P. Harris et al. (2014)

Separation distances GH2, 862bar storage, 100 kg, 10 mm pipes with a barrier wall	
Lot lines:	7,3 m
Public streets, alleys:	7,3 m
Parking (public assembly):	4,0 m
Buildings (sprinklers, fire rated):	3,0 m
Building openings or air intakes:	7,3 m
Parking from fill concentrations on bulk storage:	3,0 m
Reference area	
Storage equipment with lot lines:	246 m^2
Storage equipment with seperation distances:	493 m^2

Table 5.1. safety distances according to A.P. Harris et al. (2014)

PROPOSALS

SPLIT:

With the analysis of the comparable case a variant is made with the public functions included. However, in the compareble case there is no hydrogen production on-site. Therefore, a larger safety distance and logistic should be taken into account.
The third proposal is a variant with bunker station and public functions. This include the following functions for the bunker station; office, electrolyser, storage MP, compressor, storage HP and dispenser. For the public there is a café and exposition and associated functions. The starting point for this proposal is the sketch concept 5 and with the results of the previous evaluations. The energy components are placed in a logical order separated from each other and disconnected from the public, to ensure that they cannot reach it and keep a safe distance. However, one of the challenges is to still create a coherent design.

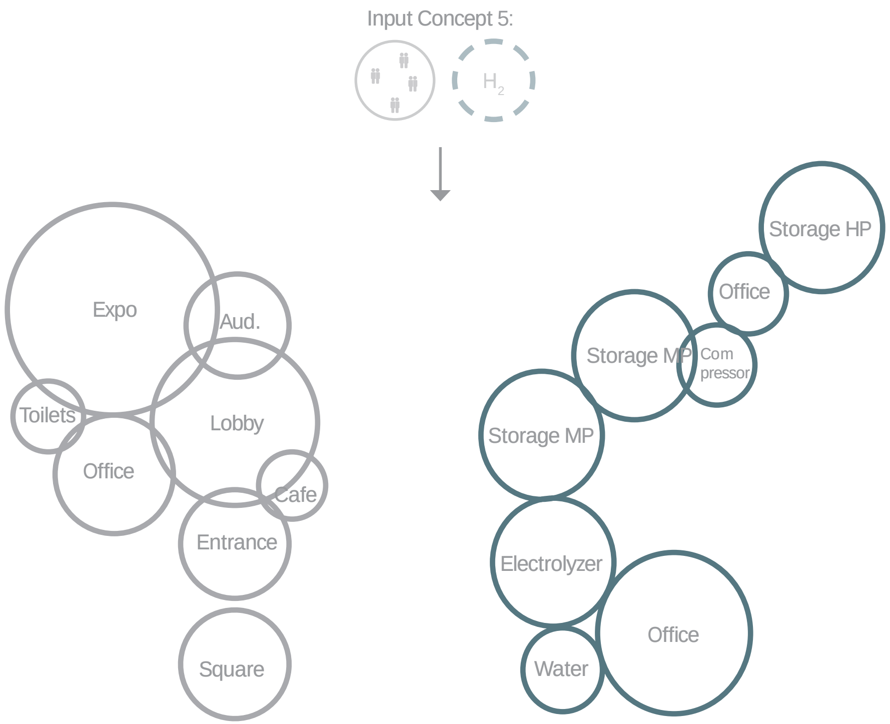


Figure 5.25. Schematic layout of the Split

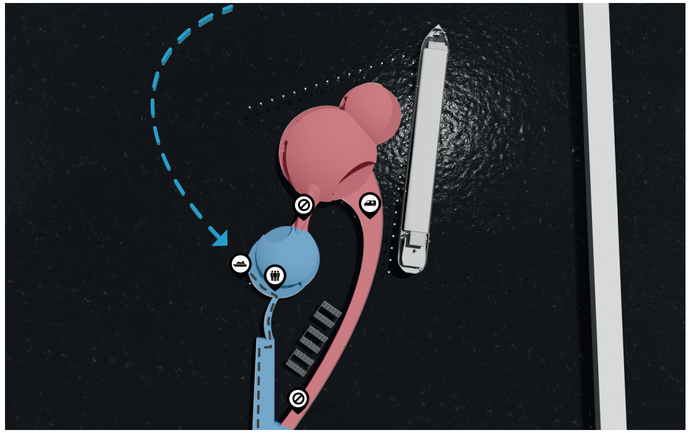


Figure 5.27. Private and public functions seperated

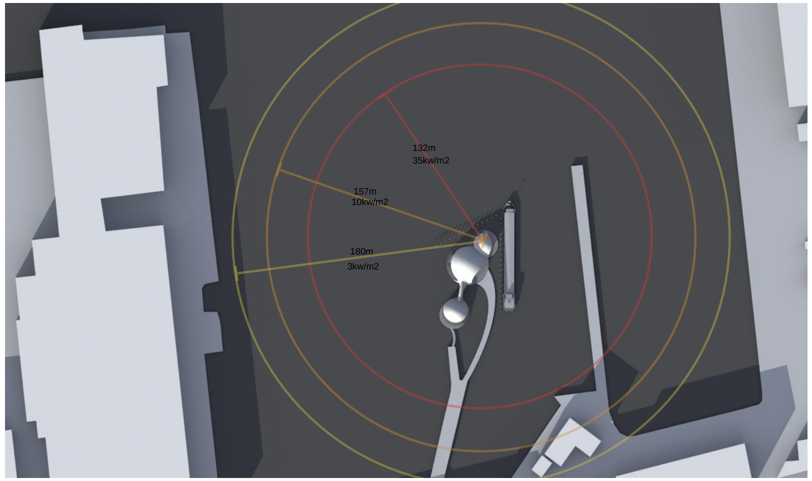
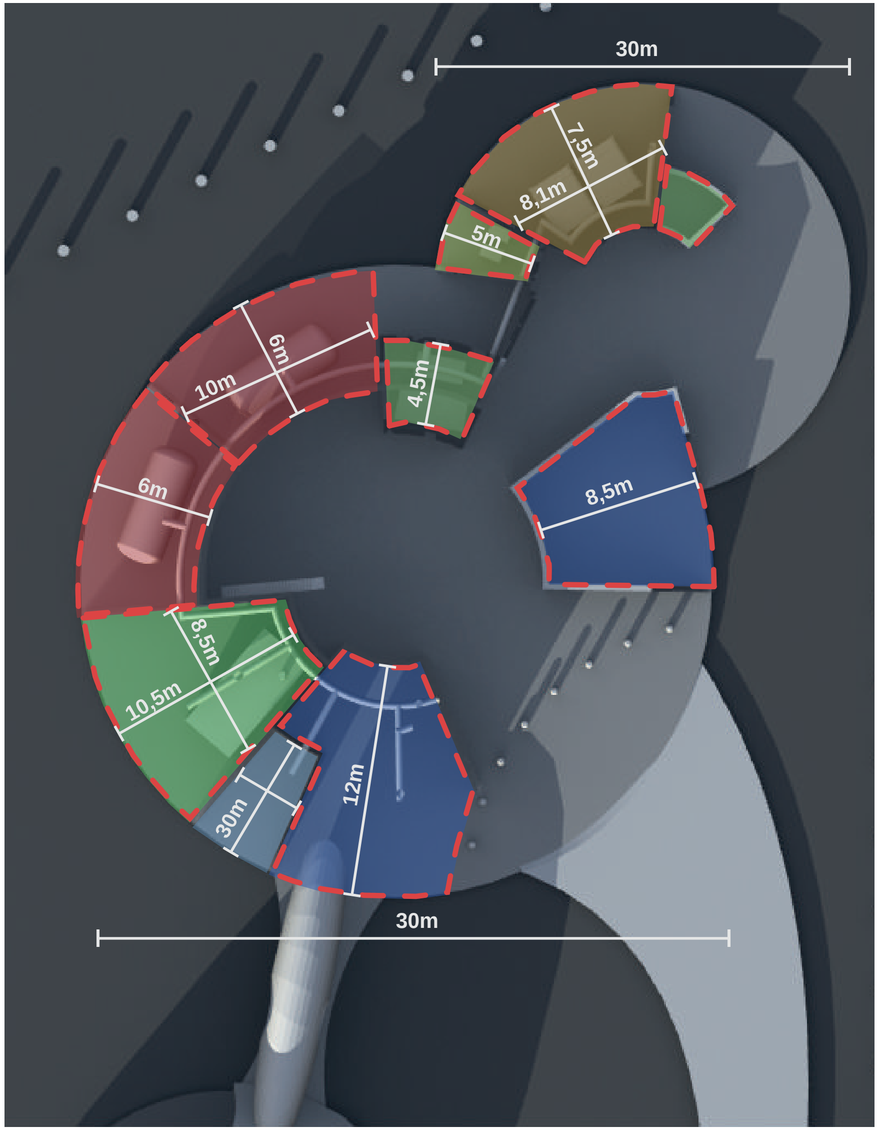


Figure 5.28.. Split effect distances according to fire department Amsterdam

The structure can be divided into two main functions, the public and private. The public sphere is located on the South connected to the existing pier, to create a distance from the private sphere. The waterbus stop is relocated on the west-side of the sphere, people travelling with the water will have to stop at the Island and walk through it to reach the RDM. The other bridge is connected to the to the private sphere, this bridge is bridge is for employees, maintenance and emergency service.

In the image to the right with the safety distances, it is shown that there will be no damage to the surrounding buildings if a crack occurs of 100mm with the applied 350 bar storage. However, the public function is located within the red circle. However, the assumption can be made that the distance will be a bit smaller because the storage is sheltered by fire resistant glass.

The energy system whole energy system is located in the private sphere, with the exception of energy production of solar panels and wind turbine. On the south is the start of the energy system, where the electrolyser and water pump is placed and also the air intake. The produced hydrogen will travel to the to the storage MP, in this proposal this storage is divided into two smaller storages. The hydrogen will from here on compressed to 350bar, stored and ready to be bunkered when the ship arrives. All the components are separated from each other from each other by a fire-resistant barrier. From the previous evaluation, it became clear that is important to showcase the energy system. Therefore this is located on the side of the circle, where it is visible from the side. However, from the results of the Wave it was shown that the storage cannot be directly exposed to the outside, especially on the side of the waterbus. A fire-resistant glass is placed to solve this problem to protect the people travelling. On the right maintenance and emergency service can arrive, there are posts placed, to protect the energy system from impact of the vehicles.



Legenda

PEM electrolyzer
Water buffer
Office
Battery bank
MP storage
Compressor
HP storage

Figure 5.29. Split energy components plan

As mentioned before the energy components are placed in a logical way, the same applies for the air system. This energy system is a elaboration of the energy system of the Droplet. The air intake on one side and the exhaust on the other side, so no polluted air will blow into the electrolyser and ventilation system. There are two air intakes one for the electrolyser and the other intake for ventilation of the Island. The air ducts is running from one side through all the energy components to the to the exhaust.
From the inside there is a stairs that goes up, this is where employees easily can check the energy components from above and the air handling units. Another important result from the previous evaluation is that there were no space replacing (sub-)systems. In this proposal each component have enough space to be replaced in it whole.

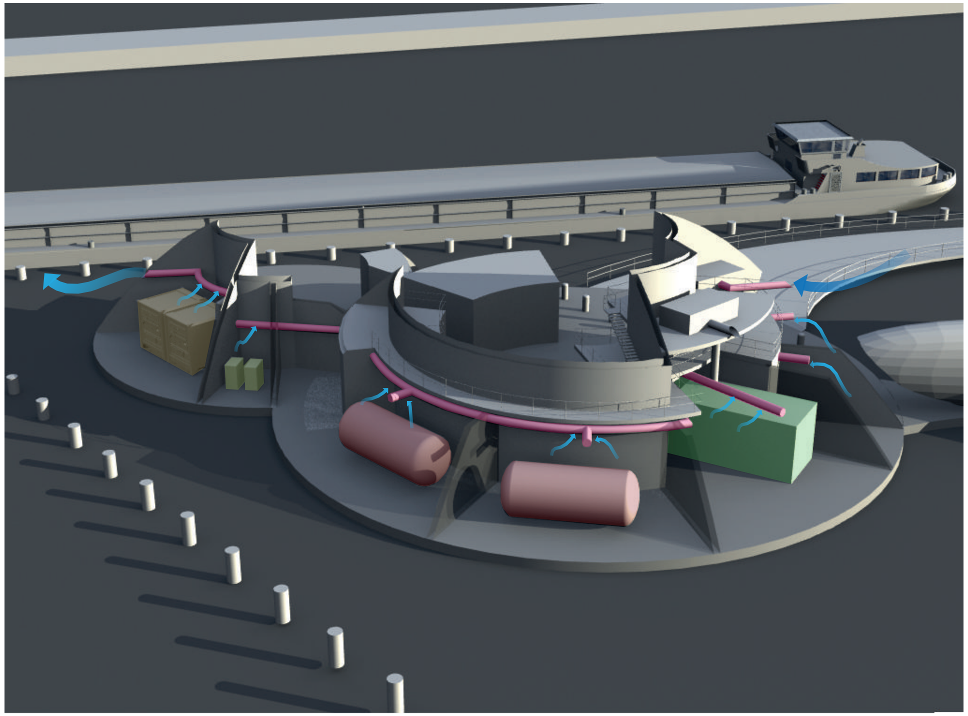


Figure 5.30. Perspective energy system of the split

EVALUATION (AIR LIQUIDE)

The proposals Droplet, Wave and Split were presented to Jaap Oldenziel, Public Affairs Manager of Air Liquide. They have realized one of the hydrogen fuelling station in the Netherlands. The purpose of this evaluation is to see how realistic the proposals are and what kind of safety interventions they have made and how they have obtained a permit.

The first commentary that Jaap Oldenziel made was; why are all the proposals closed and he suggested that it was a lot cheaper and more reliable to make it open.
Apart from the installation safety interventions Air Liquide did the same for their fuelling station in Rhoon, the most important safety intervention is the roof. This roof guides the wind to ventilate the open fuelling station. Around the station there are vehicle impact protection. Almost direct to the station there is an office stationed. The biggest challenge for them obtaining a permit was the noise of the compressor. The safety distances that were presented are quite high according to Jaap Oldenziel. He stated that, if there is a leak it will always go straight up. For the exact internal safety distances a QRA need to executed. Jaap Oldenziel assumes, with his knowledge, that it should not be a problem to realize the Island,at least as the safety requirements are fullfilled.

Summary

Jaap Oldenziel is quite positive that it can be realized. He clearly purposed that the system should be open and naturally ventilated. And something must be done to the noise that is generated by the compressor.

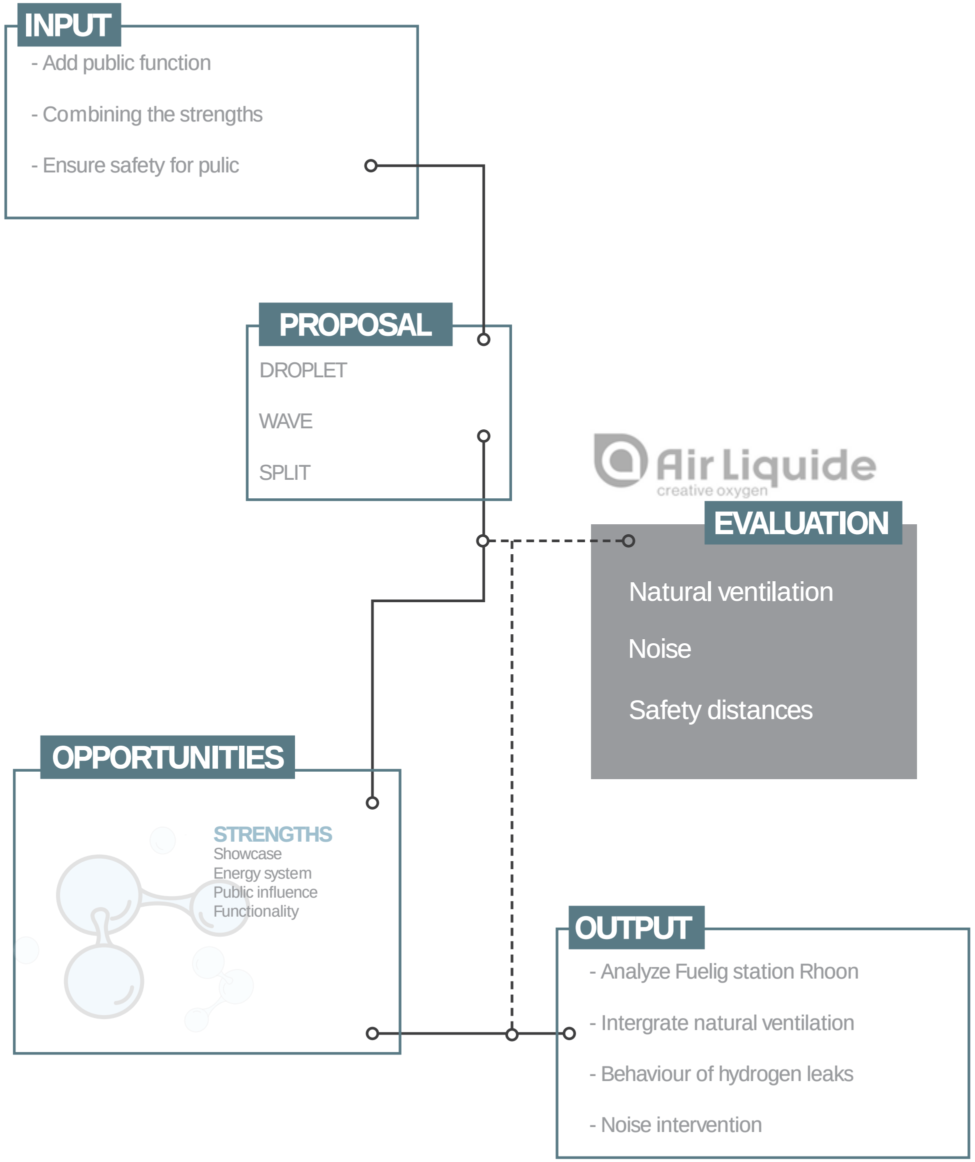


Figure 5.31. Third phase diagram

5.5 Fourth phase (Further research)

INPUT

The input for the fourth phase is to further elaborate proposal the split, with the results of the evaluation with Air Liquide. But first, a small research of hydrogen leaks behaviour will be researched to get a better understanding of why it should be open and what the impact can be on the effect distances. The hydrogen fuelling station will be analysed to see how the intervention are applied in that particular case.

ANALYSIS

Diffusivity
Hydrogen has a very quickly diffusivity, 3,8 times faster than natural gas, meaning that when it is released, the hydrogen dilutes rapidly into a non-flammable concentration, it rises at almost 20ms/s. Therefore, except a ceiling, failing ventilation system or some structure containing the gas, the laws of physics cause the hydrogen not lingering near a leak. In brief, the hydrogen can only become a fire hazard if it is confined and because it is the lightest element of the planet, confining hydrogen is very complicated. The design can help the hydrogen escape up into the air from the users in case of a unexpected leak.

Combustion
Similar to any other fuels, hydrogen can ignite. However, it is difficult to create a combustible situation, due to the diffusivity, buoyancy and small molecular size. An adequate ratio of hydrogen, an ignition source and the right amount of oxygen have to be present at the same time, in order for a hydrogen fire to occur. Hydrogen has a flammability range between 4-74% in the air and to ignite the hydrogen an energy is required of 0,02mJ. On the other hand, concentrations below 10% the energy required to ignite hydrogen is a lot higher.

Explosion
An explosion cannot happen in a storage that is only containing hydrogen, oxygen have to be present in a concentration of at least 10% pure oxygen or 31% air. The range of hydrogen to be explosive is 18,3-59%, this range is quite wide, however, gasoline have the potential to be more dangerous, because it can explode as much lower concentrations. Additionally, there is almost no possibility that hydrogen will explode in the open air, because it tend to rise rapidly. Opposite counts for heay gasses, such as gasoline fumes, which hover close to the ground creating a higher risk of explosion

Below a comparison of fuel leak and ignition is made by Swain M (2001). On the left a hydrogen car and on the right a gasoline car. A picture of a video that compares fires to a ignited, gasoline fuel line leak and hydrogen tank leak. After 1 min the hydrogen flame becomes smaller, while the fire of the gasoline car becomes intenser. After 3 min, all of the hydrogen was burned out leaving the interior of the car undamaged, the maximum temperature inside the back window was only 20ºC, The gasoline car continue burning for a couple of minutes and was completely destroyed.

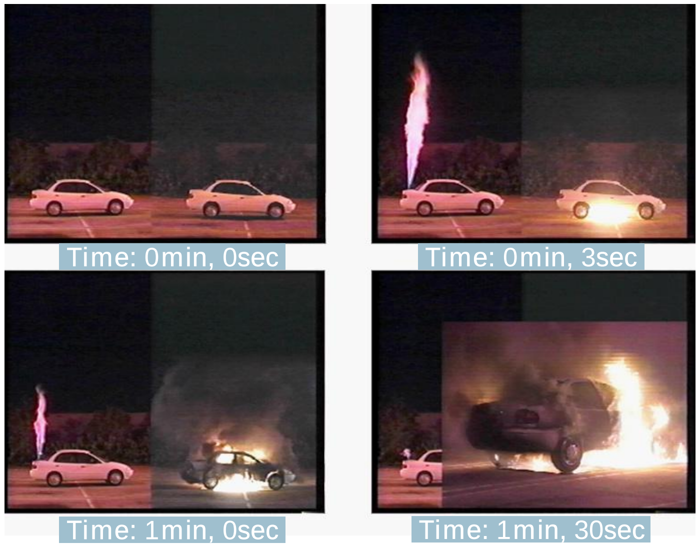


Figure 5.32. Comparsion hydrogen and gasoline car by Swain M. (2001)

HYDROGEN FUEL STATION RHOON:

Air liquide has realized a hydrogen fuelling station for the public in Rhoon and Jaap Oldenziel stated that they have done some interesting interventions to obtain a permit. Therefore it can be useful to analyse the already operating fuel station. The station is located on top of a hydrogen pipe of Air Liquide, the station is a small branch of this pipe line. Compared to the Island the hydrogen is not produced on-site. The middle-pressure hydrogen of the pipeline is compressed and stored in high-pressure tubes before it flows to the dispenser. The compressor is located in the middle of the structure and it is the only component that is closed. To obtain a permit the noise of the compressor must be reduced to permissible requirements. Next to the station is a office located, which was an old construction shack, 70m further the ANWB office is located.

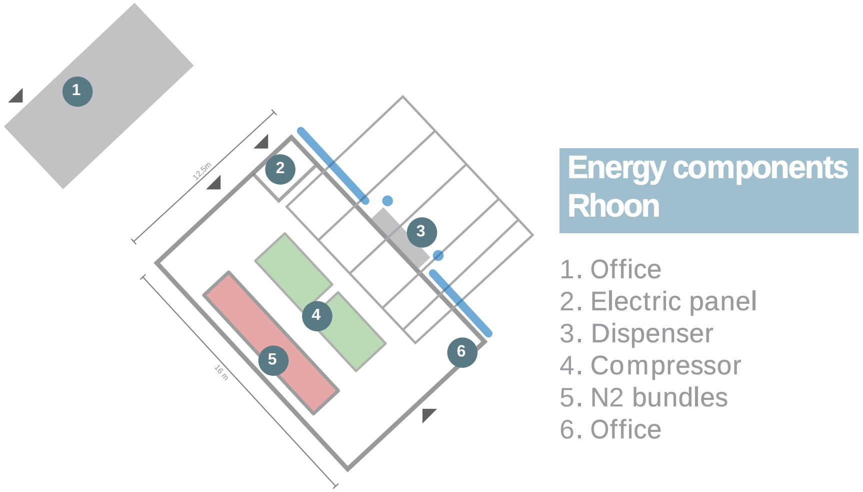


Figure 5.33. Layout Fuel station Rhoon by Air liquide

There is a large roof structure on top of the dispenser, because of the open energy system the hydrogen must be well ventilated. Air liquide have made this possible by placing a roof, which creates a small venturi effect. The hydrogen will be ventilated and any containment will be prevented. This is a simple intervention and relatively cheap. Compared to mechanical ventilation, the main advantage is that it is reliable there is “always” wind. Mechanical ventilation can break down and a lot of maintenance is required.

Figure 5.34. Ventilation principle Fuelstation Rhoon by Air liquide
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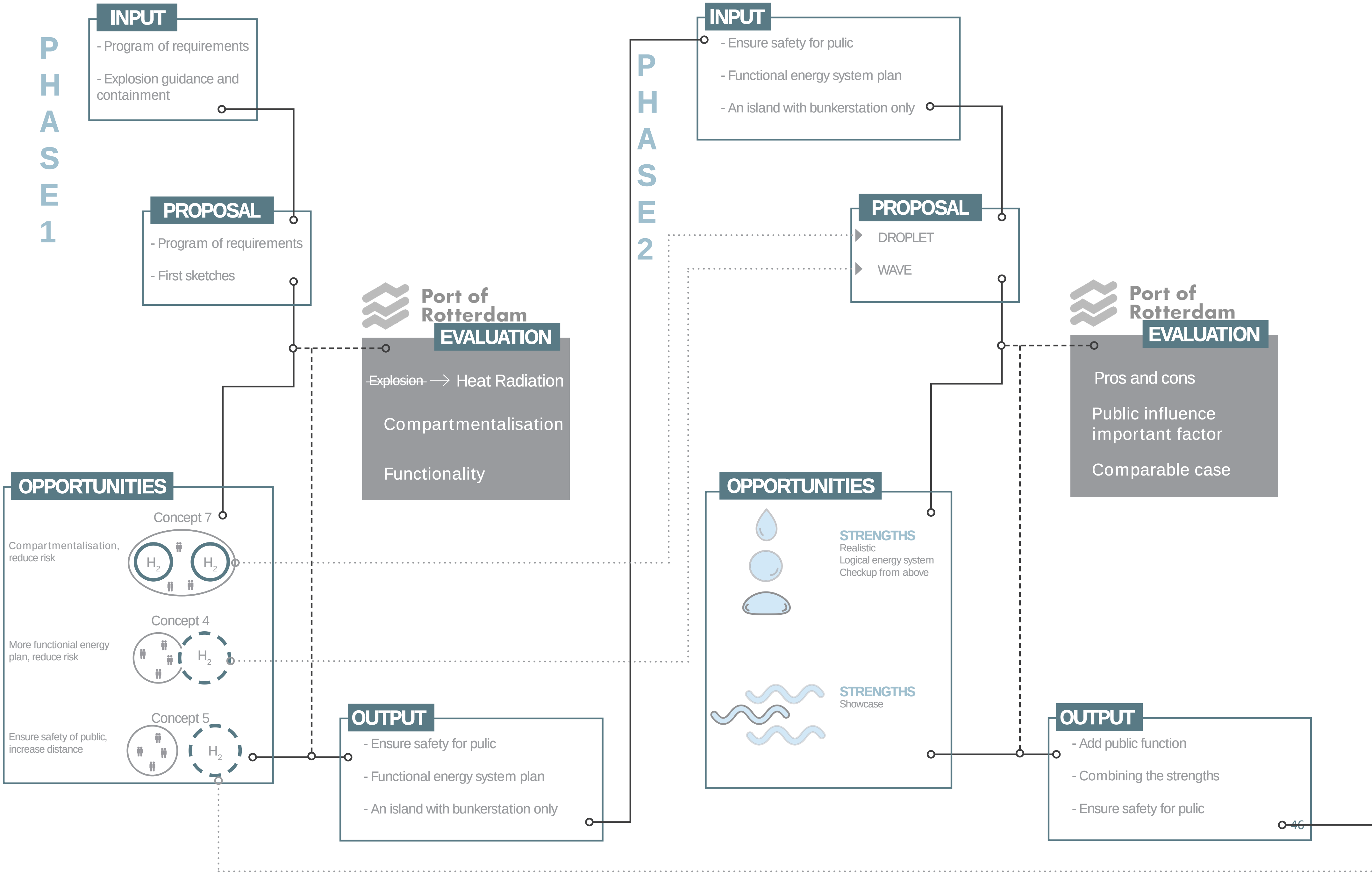

PHASE 1
INPUT
- Program of requirements
- Explosion guidance and containment
PROPOSAL
- Program of requirements
- First sketches
Port of Rotterdam
EVALUATION
~~Explosion~~ → Heat Radiation
Compartmentalisation
Functionality
OPPORTUNITIES
Concept 7
Compartmentalisation, reduce risk
H2
Concept 4
More functional energy plan, reduce risk
H2
Concept 5
Ensure safety of public, increase distance
H2
OUTPUT
- Ensure safety for pulic
- Functional energy system plan
- An island with bunkerstation only
PHASE 2
INPUT
- Ensure safety for pulic
- Functional energy system plan
- An island with bunkerstation only
PROPOSAL
DROPLET
WAVE
Port of Rotterdam
EVALUATION
Pros and cons
Public influence important factor
Comparable case
OPPORTUNITIES
STRENGTHS
Realistic
Logical energy system
Checkup from above
STRENGTHS
Showcase
OUTPUT
- Add public function
- Combining the strengths
- Ensure safety for pulic

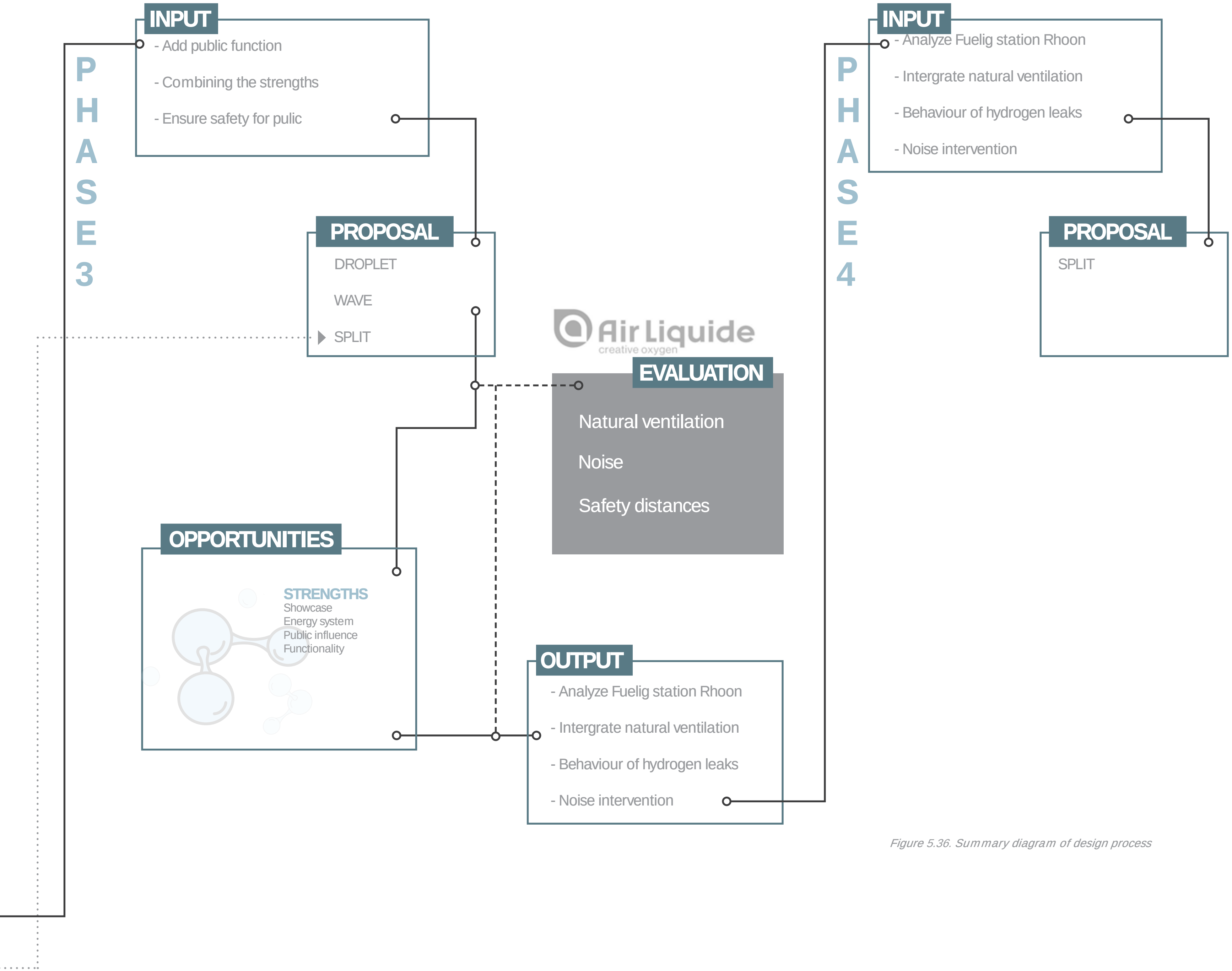


Figure 5.36. Summary diagram of design process

Chapter 6
Hydrogen effects and guidelines

6.1 Introduction

In this chapter the risks and the hydrogen accidents effects are discussed, with the effect distances according to the Brandweer of Amstelland and a list of safety guidelines is made.

6.2 Hydrogen accident effects

Hydrogen applications on the Island and the risks

1. Production
2. Storage
3. Transport
4. Use

An important aspect of a hydrogen incident is that a flammable mixture can be formed with air and when exposed to an ignition source, can lead to fires or deflagrations (explosive combustion). This should be taken into account when opposing the incident.
Incidents in hydrogen applications are mainly caused by damage to the production, storage, transport and use. The way in which damage can occur can vary per hydrogen application. The damage that occurs is comparable for the various hydrogen application according to fire department Amsterdam.

There are a variety scenarios that can occur in incidents involving hydrogen applications. The scenarios described in this paper do not distinguish between production, storage, transport and use, the size of the effect area depends mainly on the quantity hydrogen and the pressure with which the hydrogen is stored. The different scenarios are described below:

Substance	Scenario	Damage
- Hydrogen (gas) (pipes)	- Out flow from pipeline without ignition	- Ignition - Headache, drowsiness, breath-lessness and unconsciousness (by oxygen displacement) ·
	- Outflow from pipeline with direct ignition: torch fire (+ fireball)	- Secondary fires - Burns
	- Outflow from pipeline with de-layed ignition: gas cloud ignition (+ torch fire)	- Secondary fires - Possible pressure effects - Burns - Lung damage by inhalation of hot combustion gases
- Hydrogen (gas) (compressed storage)	- Outflow from pressure container without ignition	- Ignition - Headache, drowsiness, breath-lessness and unconsciousness (by oxygen displacement)
	- Outflow from pressure container with direct ignition: torch fire (+ fireball)	- Burns - Secondary fires
	- Outflow from pressure container with delayed ignition: gas cloud ignition (+ torch fire)	- Secondary fires - Possible pressure effects - Burns - Lung damage by inhalation of hot combustion gases
	- Explosion pressure container	- Secondary fires - Possible pressure effects - Lung damage by inhalation of hot combustion gases - Fragmentation damage

Table 6.1. Effects of damage to the hydrogen system according to brandweer Amstelland

6.3 Hydrogen effect distances

Damage	Description
- Crack till 5 mm	- Caused by corrosion and leaking flanges
- Crack till 10 mm	- Caused by external impact
- Crack larger than 100 mm	- Often the result of mechanical external impact
- BLEVE	- Often the result of overheating by fire

Table 6.2. Description of damage that can be caused

In case of incidents with hydrogen applications, certain effect distances should be taken into account, in order to ensure their own safety and that of others. The effect distance are mainly determined by factors such as leak size, pressure, quantity and meteorological conditions. For now presented data is standardized and presented below by Brandweer Amstelland. A more detailed calculation should be performed to obtain the exact effect distances.

Minimum distances in meters for the scenario of a 5 mm crack followed by fire:

Pressure (bar)	Length flame (m)	Heat radiation (m) 35 (kw / m^2)	Heat radiation (m) 10 (kw / m^2)	Heat radiation (m) 3 (kw / m^2)
100	4	4	5	7
200	5	6	8	11
300	6	7	10	13
350	7	8	11	15
400	8	9	12	16
500	9	10	14	18
600	10	11	15	20
700	11	12	17	22

Minimum distances in meters for the scenario of a 10 mm crack followed by fire:

Pressure (bar)	Length flame (m)	Heat radiation (m) 35 (kw / m^2)	Heat radiation (m) 10 (kw / m^2)	Heat radiation (m) 3 (kw / m^2)
100	7	8	9	13
200	10,5	11	15	19
300	13,5	14	19	25
350	14,0	15	21	27
400	14,5	16	22	29
500	17,5	19	25	34
600	19,5	21	28	37
700	21,5	23	31	39

Minimum distances in meters for the scenario of a 100 mm crack followed by fire:

Pressure (bar)	Length flame (m)	Heat radiation (m) 35 (kw / m^2)	Heat radiation (m) 10 (kw / m^2)	Heat radiation (m) 3 (kw / m^2)
100	56	63	78	95
200	85	95	112	137
300	105	121	143	170
350	115	132	157	185
400	125	140	170	200
500	145	158	185	216
600	160	175	205	240
700	170	190	220	260

6.4 Hydrogen safety guidelines

Introduction

As above mentioned hydrogen applications are not risk free. Measures have to be tanken to limit those risks. These are divided into various links of the safety chain: pro-action, prevention, preparation and repression. This list is composed of Tongeren G. (2015) and Brandweer Amstelland.

Pro-action

This is a structural prevention of unsafe situations. A possibility is to link up with the external safety policy of the national government for hydrogen applications. In short, this means in case of spatial decisions and granting environmental permits can be tested against the standards for external safety. In the context of the external safety policy, the fire brigade has a advisory role. Examples of pro-action are:
- Storage space or storage areas of the hydrogen installation must not be accessible to unauthorized persons
- Good spatial planning
- Apply safety distances (zoning)
- Sufficient space for the replacement of part systems.
- Inherently safe design
- The dispenser must adjoin the outside to a non-hazardous area as defined in NPR-7910-1
- Design that does not allow the hydrogen to accumulate and form a explosive mixture.
- Where necessary, the installation components must be protected against collision in an effective manner.
- The pipes of the hydrogen installation, under high pressure should preferably be installed above ground. If this is not possible, these pipes may be laid in a dry, preferably open, gutter or protected underground

Prevention

Prevention is to limit the chances of accidents and fires to limit consequences by implementing measurements. It is therefore important that one initiator of hydrogen applications has a risk analysis carried out to determine to which safety level the application must meet. Then the results can be taken in the design and construction. Examples of preventive measures are:
- The hydrogen delivery installation must be placed on a surface made of non-flammable material
- Applying safety valves to prevent explosion
- Earthing of the storage tank
- Execute explosion-proof electrical installations in the vicinty of the hydrogen storage
- Application of coating an cathodic protection to prevent corrosive and chemical aggressive conditions
- Take care of an incombustible surface
- No storage of combustible materials in the immediate vicinity of the hydrogen storage
- Avoid from being irradiated by external heat sources
- Sufficient distance to (openings of buildings)
- The pipes and connecting elements must be protected in such a way that mechanical or thermal damage is prevented
- Above ground pipelines should be indicated where these pipes are located and it must also be ensured that the load by the ground itself and / or the masses placed not affect the pip, preventing the pipes to be exposed to mechanical stresses.
- In a hydrogen storage the maximum volume must not exceed 95% of the actual tank volume. The expansion of the substance during filling must be taken into account.

Preparation

This is the preparation for opposing possible incidents. Here a distiction can be made by preparation by the initiator and government. Preparation by the initiator consists mostly of the operation of an emergency organization. Examples of these are:

- Having staff educated and trained to during an incident
- Having a clear escape plan

Preparation by the government mainly consists of knowing where the initiatives of hydrogen applications are localized. For this purpose the use of information provided by the environmental departments available from the competent authority. Furthermore, the corps can provide the contents of this to use for drawing attention cards that can be used as the first aid in an incident with hydrogen.

Repression

Repression is the actual fight against the incident. A division can also be made here between the role of the initiator and the government opposing hydrogen incidents. The initiator knows the application and knows what the possibilities and impossibilities are to limit the size of the outflow. Only specialists are able to repair a damage. Every initiator of hydrogen applications therefore, an emergency plan should be available. In the event of a (large-scale) incident, close collaboration will have to take place between fire brigade and initiative, since the fire brigade has the operational management of the incident control. The specialists of the initiator will, in consultation with the officer of the service, fight the source to carry out. The deployment of government emergency services in (large-scale).

- Sufficient space required for safe access for road vehicles, vehicles for the supply of hydrogen and emergency vehicles.

Chapter 7
Design requirements

7.1 Introduction

In this chapter the final design requirements are presented, these are the final results of the safety guidelines research and outcome of the elevation sessions of the design process. If the building meets all these requirement, it can be stated that the building will be more safe and efficient with the aim of eventually obtaining a permit. This can also be used as a guideline for other project involving hydrogen.
The design requirements are divided into different categories:

- Location/context
- Logistics
- Social impact
- Functionality
- Prevent accumulation
- Maintenance
- Noise
- Structure/form
- Energy production

In the following section these categories are described, acting as a starting guide for the final design.

7.2 Location/context

Safety contour

In, 2014 safety contour were established for the Botlek-Vondelingenplaat, Europoort, Landtong, Maasvlakte 1 and Maasvlakte 2. The establishment of safety contours have been a part of the provincial policy. In the Space and Mobility vision, the province Zuid-Holland is focusing on clustering possible risky activities in suitable areas. This limits the amount of people exposed to the possible risks, which is beneficial to safety. The port area is suitable for clustering high-risk functions. However, within a safety contour a limited amount of vulnerable objects are allowed, unless these are functionally bound to the area for which the safety contour has been established. An exception is made for existing limited vulnerable objects. Due to the implementation of the safety contour, it is clear for the urban environment to where the location-based risk contours are limited (Commissiemer, 2015).

On the image on the next page an image of the safety contour is shown. The safety contour runs from the transition Droogdokweg/Heijplaatweg and Directiekade towards the Dokhaven, from the Kraanbaan through the Dokhaven to the Nieuwe Maas and branches off the head of the Sluishesdijkpier. Placing of the safety contour, the RDM campus has been taken into account. With this clear boundary condition the Island have to be located outside the safety contour to avoid complications with the Province Zuid-Holland.

Figure 7.1. Safety contours the Waalhaven

Plan description

With the determined safety contour, it does not mean that the Island can be located anywhere outside the contour. There is a clear Stadhavens program where The Waalhaven is a part of. This area will continue to innovate, modernize and intensification of the existing industry in the coming years. Progressively there will be more maritime services and port-bound office development. In the South and East of the Waalhaven an advanced service cluster for the maritime industry arises. The former RDM yard is transforming into one innovative centre for technology and education. The village of the Heijplaat, in the middle of the area, is partly renovated and modernized with new facilities (gymnasium, supermarket). Balance between working and living in The Waalhaven is fundamental. The village Heiplaat is also in a transformation process. The objective of this transformation is to keep the level of facilities up to standard. The RDM terrain should also be connected to the residential area to develop Heijplaat into contiguous neighbourhood.

Zoning plan

In the zoning plan, established in 2016, the plans for the port area are determined on the basis of divisional division used by the Port of Rotterdam. This plan is divided into the following categories such as “continuation locations”, “development locations” and “office locations” to indicate where or how the development of the area will occur. The categories that fit the Island is “development locations”, these are issued plots that are free or a current activity takes place and where another type of activity can be developed in the zoning plan period. Whether the current activity in the planning period is shifting or replaced by another activity depends on various factors. For example, the economic role plays a part, what are the demands from the market.

Figure 7.2. Suiting lots for the Island

From all of the available development locations there are two possible suiting lots. These two lots are outside the safety contour and still have a central location for the access of the Inland ship and at the same time easy accessibility for the public. But also have a sufficient distance from the surrounding buildings. However, within these locations changes are limited. There can be an extension of the current use, another use is permitted within the plan period. The plans for these two lots are Maritime service industry, this is divided into two sub-segments;

- Maritime industry: companies that provide services and products to sailing objects to keep them operational. It concerns repair and conversion of ships.

- Maritime services: companies that provide services to ships to ensure safety in and out of the port.

These are sub-functions of the Island, the Island falls under the sub-segment Gas & Power, because of the production and bunkering of the hydrogen on to the Inland ship. The Island is suitable for half of the zoning plan, therefore to realize the Island on this location the plan have to be adjusted. This will only happen if it meets the following requirements, there have to be sufficient market demand, ensured safety for the surrounding buildings and people and a positive influence on the residential area.

7.3 Social impact

RDM

On the RDM north of the Heijplaat, formerly a large shipyard, alongside the maritime industry there is an increase of maritime services. In addition, more port-related educational institutions are also being established. The abbreviation RDM, formerly for Rotterdamse Droogdok Maatschappij, now stand for Research, Design and Manufacturing.
Port activities are gradually changing into a mix of work a education. RDM Innovation Dock is the driving force behind this development. The RDM campus has now been realized here. Under the motto Research Design and Manufacturing, this area is being developed into a unique location and incubator for the creative and innovative manufacturing industry and for new energy carriers. The Albeda College and Rotterdam University are located here. The submarine hangar is one of the initiatives of the Port of Rotterdam to bring a broad public in contact with the port and to strengthen the quality and experience of the port area, it is used for exhibitions and conventions.
The schools and the companies that are located here, form an international icon for creative and innovative activities focused on building, moving and powering. Colleges, technology companies and innovative manufacturing industry reinforce each other in the search for sustainable concepts for energy generation and usage and urban water management. Together with the laboratory on the other side of the Maas, RDM is a breeding ground for the Clean Tech Delta.

Mentioned above the RDM is a perfect location to showcase and develop new sustainable energy projects. One of the social objective of The Energy Island is to show that hydrogen is a safe energy carrier with a considerable amount of advantages. However, a lot of people are still doubtful, in particular an association with the Hindenburg disaster on May 1937 (ARIA, 2009). In other words the public acceptance of hydrogen is required to penetrate the market and make hydrogen a conventional energy carrier.

According to OECD (2002) it is obvious that the approach in which environmental benefits are used as the only advertised “selling aspect” for hydrogen seems not to be a very successful approach. This approach is not appealing to enough people that are not directly affected by the problem. They also performed a study and developed a list of particular boundaries:

- Lack of awareness of the need for change
- Cognitive dissonance
- Lack of concern for future generations
- Fear of and thus resistance to change
- Lack of adequate professional advice

In the following model developed by I. schulte, D. Hart and R. van der Vorst (2004). This is to visualise and summarise the components that influence the opinion forming process.

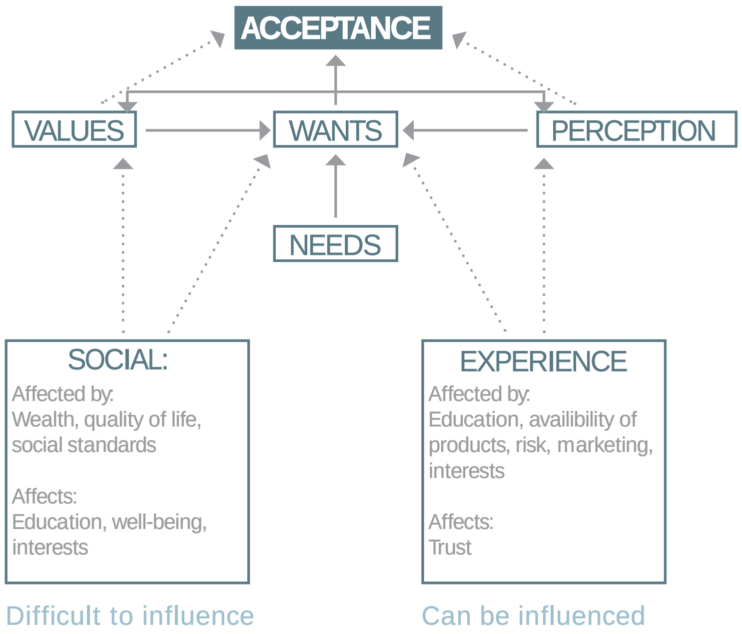


Figure 7.3. Acceptance model, developed by I. schulte, D. Hart and R. van der Vorst (2004).

The factors of acceptance is explained by I. schulte, D. Hart and R. van der Vorst (2004) in the following way:
- Perception; The perception of different products, events or topics usually depends on previous experiences. Additionally, an individual values can have an impact on the perception and the other way around.
- Values; On the basis of the upbringing of an individual particular qualities are found important. These are established by a particular perception of the environment and influence an individual actions and choices. Experience is able to adjust the values, by changing the perception
- Wants; People have similar unchangeable needs. Depending on values and perception expresses the form needs. Wants is directly conncected to a particular person's value. These three aspects are different from each person. They are exposed to constant change, particularly if the person is a minor and constantly learns and adapts.
The two most important components affecting the advancement of these factors are experience and social background.
- Social background; commonly this depends on the social norms and the cultural environment and wealth of the environment an individual is born into. This will determine mainly the education of the individual. Education has the greatest potential to encourage capabilities and will define their personal principles and standards.
- Experience; The degree of learning and social impact will affect the development of interest and gaining practice. The social background is very difficult to influence, this is different with experience, especially by "marketing" the experience and therefoer the perception of a product is easy influenced.

The scheme propose that the three aspects can directly have impact on acceptance. These results of person's experience and social background. Social background is a factor that cannot be quickly changed, therefore the focus for more acceptance should be on experience. The most useful components of experience that can applied on the Island are:

- Education
- Marketing
- Exposure to product

Education is a extensive topic, schools should also implement the topic of renewable energy and innovative fuels, therefore the students are aware of the available possibilities. To be able to affect the people that do not have an education anymore, informative centres can be useful. However, they have to be located in central areas to attract as

many different people as possible. This will only work if they come by the informative centre on a trip that they would already perform. This gives the opportunity for people who are not directly involved with new technologies. These activities can improve knowledge about the topic and at the same time improve the perspective towards the new technology.
Nonetheless, most people are still not interested to spend time in an informative centre even if the location is convenient.
These people may be however be affected to marketing.
"*Marketing has the ability to be very effective in improving perspectives and can be valuable approach. However, a problem in forming a marketing strategy for H2 fuel is that the initial step should be forming a general positive image instead of promoting a specific product*", as result of the interview by Dinse G. (2000). Today's largest selling point of hydrogen transportation is, how environmental friendly it is.
However as Buchan (2000) were able to demonstrate; not all people contemplate "environmental" to be a positive feature, a few people even think it will reduce the quality. The sustainbility factor of the hydrogen transportation should noted to the public, however the performance should also be specified.
For the Inland ship companies it is important to show that hydrogen ships are financially viable and that the performance of the hydrogen system are improving, which results in even cheaper hydrogen in the future.

7.4 Logistics

Public

In the previous section the importance of the social impact is mentioned and how to empower the acceptance of hydrogen. Therefore it is essential that the Island should be easy accessible for the public. This depends partly on the location. Around the RDM terrain there are enough parking spots realized free of charge, these are all within walking distance from the Island. The same applies for the bus RET bus line 68, the bus stop is located on the Heijplaatstraat, one street behind the quay. RDM also can be reached by the water taxi and waterbus. Line 18 of the water bus sails from Erasmusbrug, St. Jobshaven and Katendrecht to RDM, this catamaran sails twice in an hour. The water taxi can be reserved at various locations in Rotterdam, depending on the location where the person is coming, it is most likely that sailing with the water taxi is the fastest way to reach the RDM.

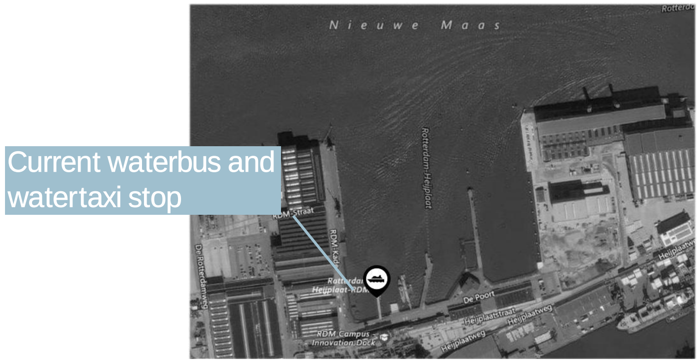


Figure 7.4. Curret waterbus and watertaxi stop

The Island can be reached by different ways, however mentioned in the previous section to attract as many people as possible the Island should have a central location. For the people that are not directly interested, it should be a stop of their trip that they would make anyway. Therefore, the waterbus and watertaxi stop should be transferred from the current location to the Island. People will be forced in a way to stop at the Island and maybe be inspired in a way. It is important that there is a clear separation of the access for the public and private. The public should keep a safe distance of the hydrogen system at all times. If an incident occurs the public should not be in direct contact and the incident must not interrupt or block the escape route of the public. The public and private (risky) functions have to be separated from each with a reasonable distance.

Services

The Island should not only by easy accessible for the public, but also for emergency services. They have to be able reach and leave the location quick and easy. Emergency service vehicles do not have any specific dimensions, whereby roads have to meet minimum requirements. The fire department has the largest and heaviest vehicle, therefore this is usually normative. The minimum available paved row width, may vary per road feature, but it should be at least 3 meter, with at least 3,5m of free space. In addition, there is also a minimum for the load ability of the road. As a guideline for pavement, for the axle load of 10 tons and a total weight of 30 tons.

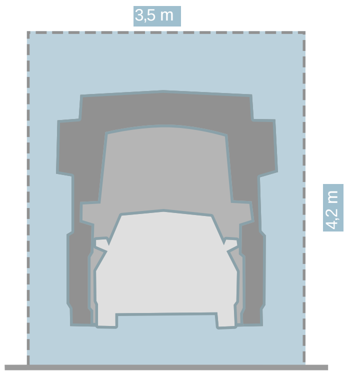


Figure 7.5. Minimum width of a fire truck according to veiligheidsregio rotterdam

For other building types besides housing, there is a maximum distance of 10 meters, from the standing position to the incident location. Furthermore, the standing position should be strategic, it should not be not located next to the building or storage that within 30 minutes of the occurring fire or accident that the located vehicle can suffer from damage of the fire of the accident (Veiligheidsregio Flevoland, 2014).

The entrance for the emergency vehicles is also for maintenance service. The vehicles can cause an accidents on the hydrogen system, collision security should be placed if there is a chance where the vehicles can come into connection with the hydrogen system.

7.5 Accumulation prevention

Risks

Discussed earlier, hydrogen is equally dangerous as other flammable substances, like natural gas and gasoline. In fact, some of the hydrogen's characteristics provide safety advantages compared to the other fuels. Nonetheless, all flammable substances should be handled carefully. Hydrogen can be dangerous under very specific circumstances, however it can be handled safely when the guidelines are analysed and the consumer has an understanding of it behaviour.
Hydrogen has a rapid diffusion, 3,8 times faster than natural gas, when there is a leak, the hydrogen dilutes rapidly into a non-flammable concentration, it rises at almost 20ms/s. It is impossible for an explosion to occur in a storage or any contained space that only contains hydrogen. There must be at least 10% clean oxygen or 41% air. Hydrogen can be explosive at concentrations of 18,3% to 59%, despite being a wide range, compared to gasoline that have a larger potential for an explosion because of the much lower concentration. Additionally, there is a very little chance that hydrogen will explode in the open due its habit to rise quickly. On the other hand a leak of heavier gases or even gasoline fumes are a much greater risk for explosion, because this will hover just above the ground (Vasil'ev V. 1999).

Ventilation

Thus, unless a poorly ventilated room, roof or structure containing the rising hydrogen gas, because the laws of physics prevents hydrogen lingering near the leak, it can only become a fire hazard if the

hydrogen is confined. To avoid any possible accumulation of hydrogen, mechanical ventilation can be installed. However, this should be a double system, if one system fails there is a back-up system, in this way there will be continuously ventilation and no chance of accumulation of hydrogen. One of the drawbacks is that because it is mechanical it is not completely reliable, there is always a chance the system will fail and a lot maintenance is required. High maintenance and a double system will lead to a high costs system. Therefore the preference goes to natural ventilation. In the analysis of the fuelling station in Rhoon, it shows that it only uses natural ventilation and a large roof structure is placed to increase this ventilation. The design can assist the hydrogen escape away in case of an unexpected release. Natural ventilation is a lot cheaper compared to mechanical ventilation, mainly because it does not require any maintenance. Furthermore, it is much more reliable, natural ventilation or wind will never stop occurring.
Which should be taken into account is that when natural ventilation is applied, it comes in direct contact with outdoors. Therefore weather protection is necessary. It should be protected from extreme temperatures, especially in the summer where the high temperatures are reached. The hydrogen system should be covered from the sun, but keeping in mind that it should be designed in a way that no build-up of hydrogen gas can happen. Additionally, the hydrogen system should be located in a strategic way, when the system is orientated as much as possible to the North, a minimal radiation will take place on the system, reducing the chance of reaching dangerous temperatures. In this way temperature will be minimized without any interventions. The structure of the hydrogen system should avoid constant exposure to water, to prevent oxidation, therefore reducing the risk of collapsing of the structure.

Sensors

The human senses will not detect a hydrogen leak, because hydrogen is tasteless, colourless and odourless. For this reason, hydrogen sensor can be placed to detect leaks. These should be placed somewhere above the system, so when a leak occurs the hydrogen will rise and pass the sensor. When the sensor detects hydrogen the entire system should have an emergency shutdown to prevent more accumulation of gas.

7.6 Functionality

The hydrogen system consist of a various components that is basically a circuit. Water, electricity and air are the starting ingredients for the electrolyser to produce hydrogen. With a small compressor the hydrogen is compressed to 50 bar storage, from the MP storage most of the hydrogen will be compressed again into 350 bar storage ready to be bunkered to the inland ship and a small part of the hydrogen will be converted into electricity through the fuel cells, the energy will be used by the building when the renewable energy production is not sufficient enough. Preferably, all of the components of the hydrogen system should be placed next to each other as close as possible, in the same logical sequence of the circuit, to avoid unnecessary the lengths of the pipes where hydrogen run through. However, the components still need an appropriate distance and separation from each other. In other words, the components should be compartmentalized to minimize the effect of an incident. If an incident occur the damage should be minimized to one component, assuming they are not located in compartments, one incident will cause chain reaction damage to all other components.
The whole hydrogen system should be located in the same part of the building, creating a “controlled risk zone”, by doing this the pipes will run through this zone and not exposed to any potential impact.

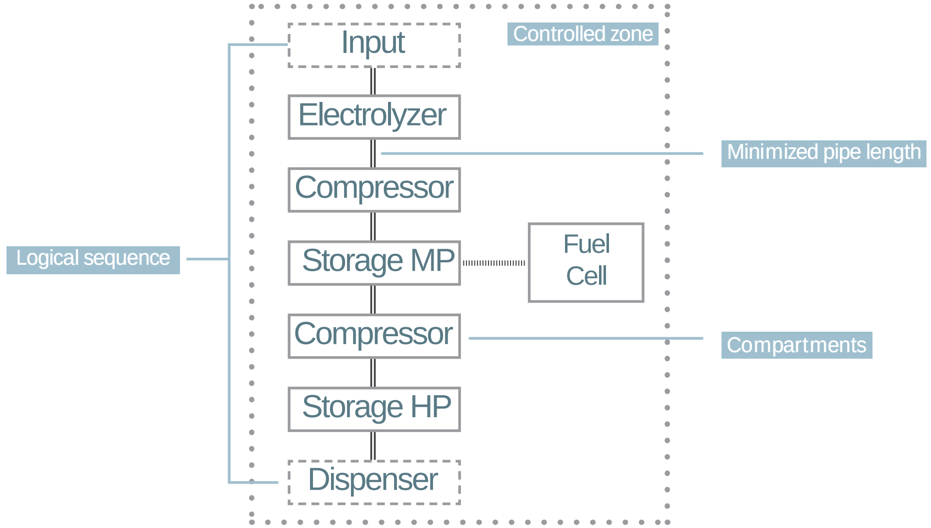


Figure 7.6. Scheme of hydrogen system functionality

7.7 Maintenance

The hydrogen system is a complicated system with a lot of connections and different components. To ensure safety each of these components should be working properly at all times. Therefore it is important that all of these components can be easily checked visually. This means that the service operator should have easy access to all components from all points, so visual checks from above are necessary as well. Sufficient space and easy accessibility will be appreciated by the operator, due to the weekly check-ups.
Besides check-ups, occasionally parts or whole components have to be replaced. The building should therefore have sufficient space to transport the components in and out the building. It is convient if the large and heavy object are placed at the ground floor, so the difficult transport is avoided.
All maintenance procedures should be operated in conformity with an approved written procedure and maintenance description should be made. The description should include details of the activities that are performed.

7.8 Acoustics

The noise zone is an area between the industry terrain and the zone contour. The external limit specifies the limit beyond the 24 hour value of the noise load due to the industrial noise of the relevant industrial site may not exceed 50 dB. Sound sensitive destinations, such as homes and schools located in the noise zone. The preferred value for the noise load on the facade of sound-sensitive object is 50 dB per zoned industrial area.
The main noise produced by the high pressure compressor, should not only disturb the surrounding buildings, but also not be a hinder to the persons working within the Island.

7.9 Structure/form

In previous sections it was discussed that it is important for the public to reach the Island. Not only accessibility plays a big role to attract people, but also the design can wake people's interest to come to the Island. The structure/design should represent what stand for the Island. For this Island essential points to show are; hydrogen production, characteristics.
In context of sustainability, the structure should have a efficient material use. But in case of a hydrogen accident, the bearing structure of the hydrogen storage must continue to fulfil its function for at least 60 minutes in case of fire according to R60 (NEN-EN 1363-1). The main support construction should be at least 60 minutes fire resistant.

7.10 Renewable energy generation

Solar panels

In context of sustainability, the Island should produce as much renewable energy as possible. On the location this can be done in two different ways, produced by wind or the sun.
Wind power energy, solar energy have similar advantages. The most essential advantages is that is sustainable, not possible to overconsume and exploiting energy does not induce pollution. However solar energy does have advantages over wind power, they do not involve moving parts, so there is no noise generated. Also present-day solar panels do not require a lot of maintenance, normally only a couple of times of cleaning is necessary. On the other hand solar power have drawbacks compared to wind power energy. Solar energy is an intermittent energy sources. Sun light is limited by night and overcast days. Therefore, by using only solar panels can lead to difficulties when it comes to balancing the energy demand. A part of the composition of solar panels consist out of materials that are rare and expensive. They indirectly cause pollution to the environment, due to the emissions of harmful substances (nitrogen trifluroide and sulphur hexafluoride), these are potent greenhouse gasses that have a great impact on global warming (Aggarwal V. 2018).
However, the decision is still made to only apply solar panels on the Island. The size and height of the Island is limited and therefore incorporate wind turbines will be not that efficient. A solution can be to place a wind turbine (with efficient dimension) on another location and extract the energy generated. Nonetheless, this solution will be separated from the design.

Integration

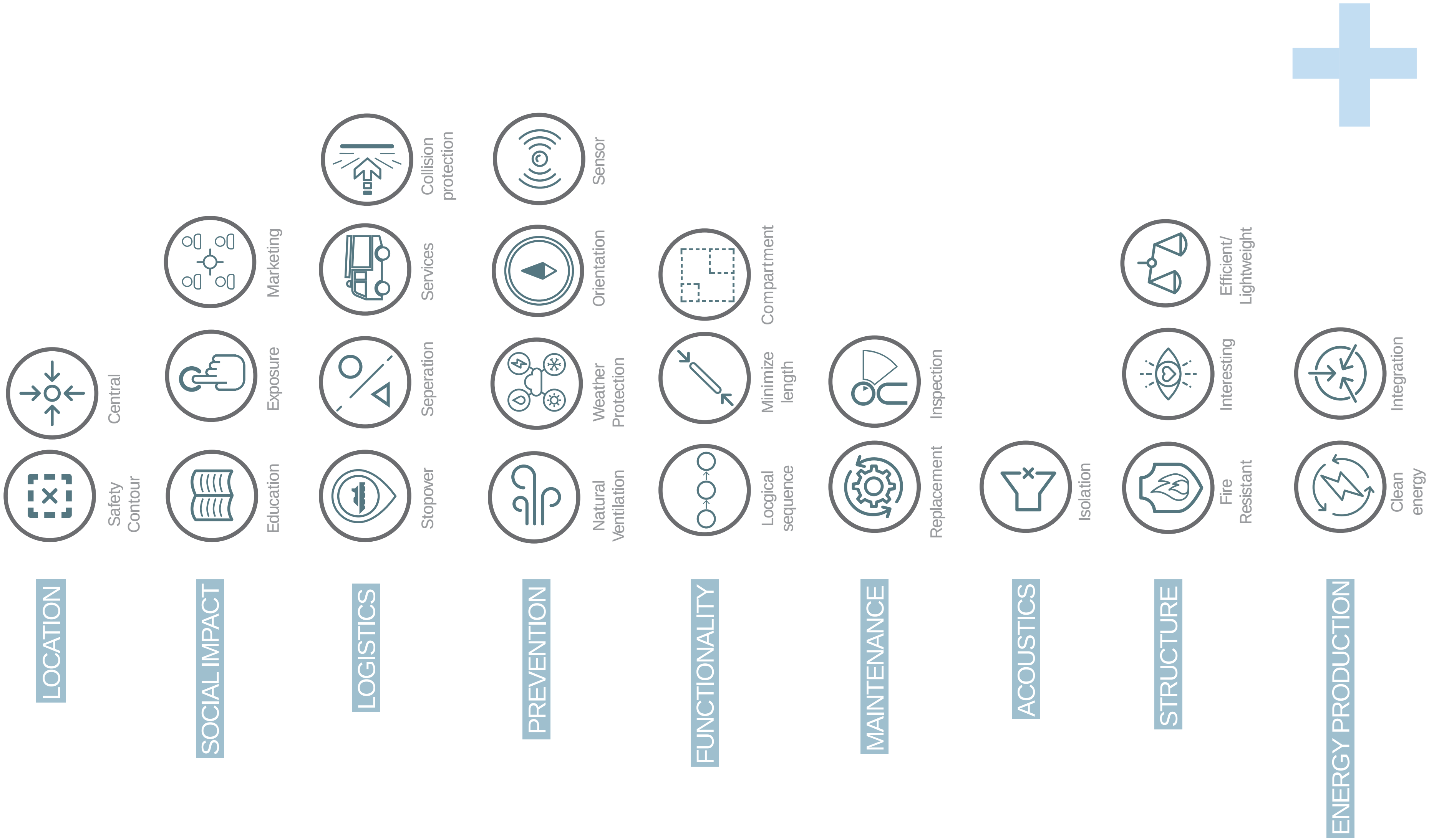
Most of the time solar panels are placed on the building as a sort of an afterthought, therefore they have an unsightly reputation. However, this is not necessary if the energy generating panels could be incorporated into the architecture.
According to ECN (2009), International Energy Agency have organised a work program, where a team of ten architects, gathered from different countries, have composed an architectural criteria for the application of solar panels in architecture. They have formed the following list:
- Natural integration of solar panels
- Panels should fit in the total architectural building concept
- Good overall composition of materials and colours
- Panels should be in accordance the pattern and lines of the design
- They should be suitable with the character of the building
- The solar panels should be integrated with the other structure
- The whole integration should stimulate innovative designs

Positioning

To reach the highest efficiency of solar panels, it is important that they have a proper positioning where most sun is captured. In general, this means that the solar panels should face south and within a angle between 20^{o} and 50^{o} (Boxwell M., 2017). However, the solar panels should be integrated as mentioned above, therefore may not be aligned in an array. It is important that solar panels are only placed in positions where they are used optimally.

7.11 Summary

THE ENERGY ISLAND



Chapter 8
Final design decisions

8.1 Introduction

This chapter the final design decisions is a follow up of the final design requirements. The established requirements are applied in the final design which is an extension of the variant “Split”. Here the choices will be further explained in detail.

8.2 Location

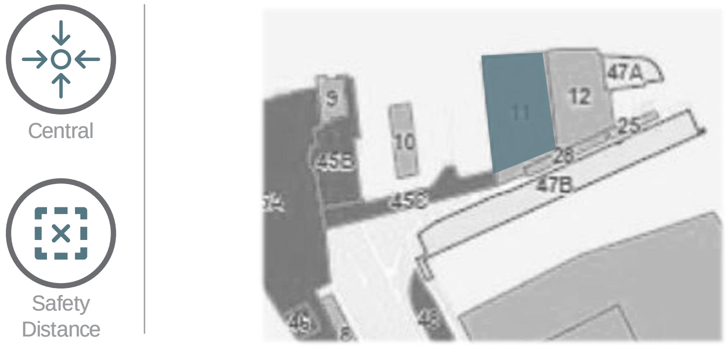


Figure 8.1., Chosen lot 11 from zoning plan (right)

The area that is chosen to locate the Island is lot 11 from the zoning plan of chapter 7.1. This choice is based on two main reasons, the location should be central accesible and visible. Not only should it be accesible for the people and vehicles, but also for the Island ship, the ship must have tolerable space to dock. Therefore the Island is placed on the egde of lot 11, which creates enough space for the ship to dock on the East side of the Island. There has to be a sufficient distance between the surrounding buildings and the Island, due to the effect distances of the hydrogen system. Lot 11 is located more on the East, which creates enough distance with the RDM campus. This is one of the most important function to keep a safe distance from, due to the high occupancy of the students during the day.

On lot 11 there is a exisisting pier between the Dokkantoor and the current waterbusstop. This will be beginning of a entrance to the Island, with a width of 6,5m it is enough to transfer persons and vehicles. However the Island can not be connected directly to this exsisting pier, this is also due to that a safe distance must attained. Therefore the exsisting pier is extended to the North, towards the Nieuwe Maas. The existing pier is extended by 40m, the length is minimzed to still have a safe distance from the quay and Dokkantoor and to have a pleasant walking distance for the public to reach the Island. If the distance to the Island is to large, people will think that the Island is “unreachable” and there is a greater chance that they will not go there.

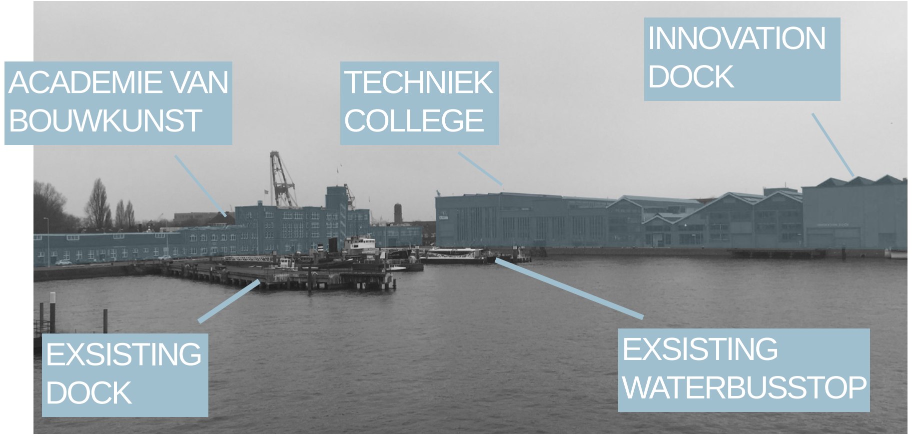


Figure 8.2., Surrounding buildings, exsisting waterbusstop and pier

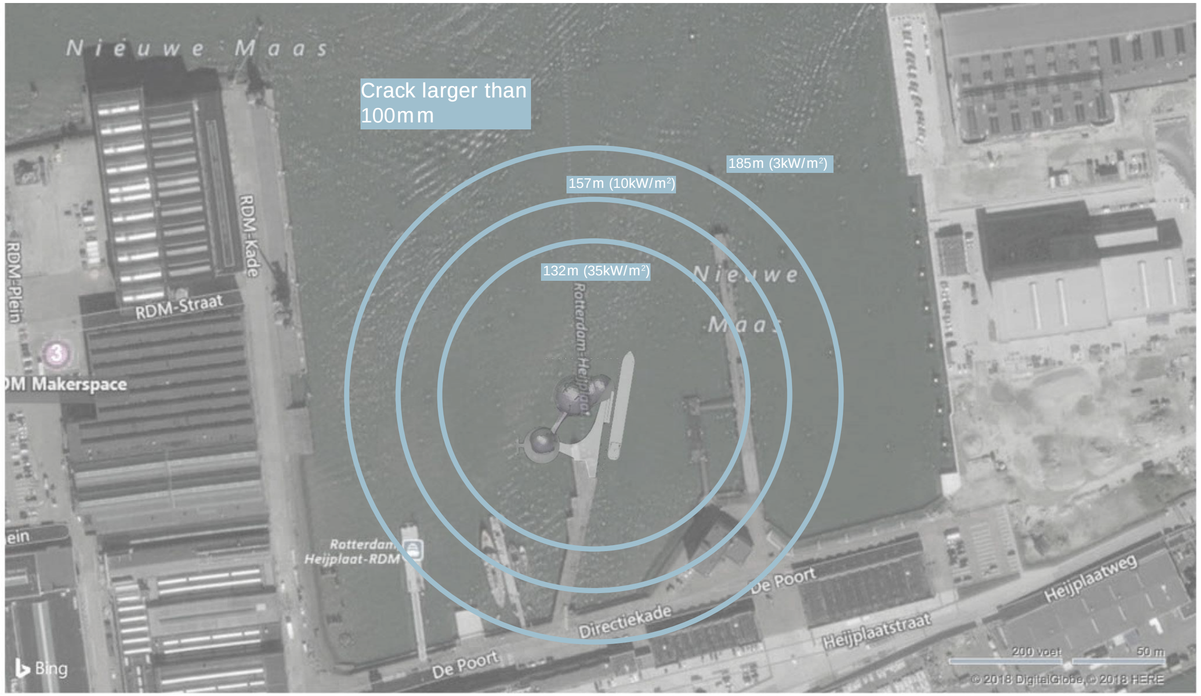


Figure 8.3., Top view of distances with the surrounding buildings

8.3 Logistics

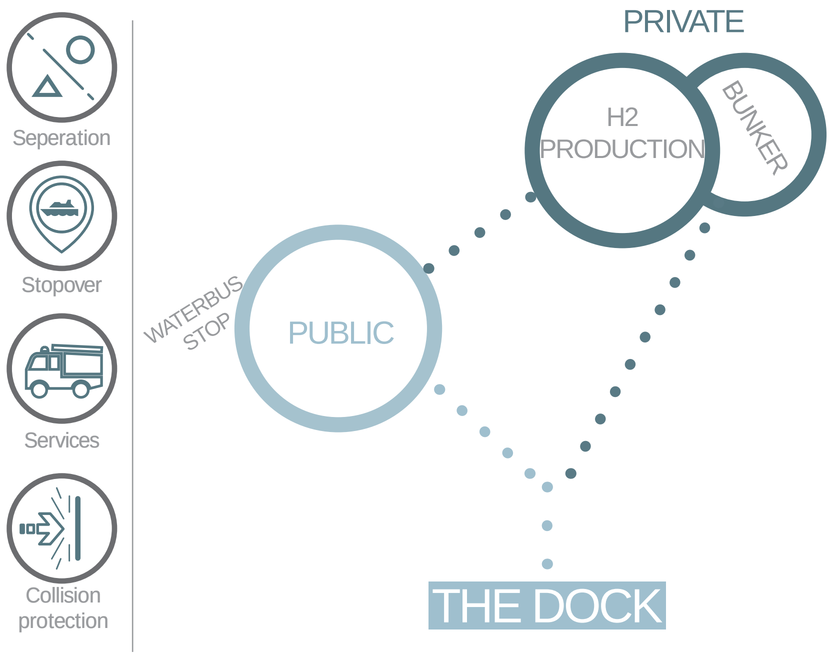


Figure 8.4., Schematic image of the logistics

The main functions of the Island or divided from each other, mainly for safety and logistics reasons. The public function is located with a safe distance from the private functions. This is located more on the south compared to the private functions, they are closer to the quay, so in case of an accident of the hydrogen system, they can be brought to safety in a faster way and because the hydrogen system is located on the North, therefore it will not block the escape route of the public in any case. Only authorized personnel can reach the private functions through the public part or directly from the dock. This extended dock is created to let emergency services reach the private part of the Island. The dimensions of the dock is sufficient enough for a fire truck. The idea is that the energy services, turn at the split, which has enough space for a fire truck, and drive in backwards with the vehicle. Maybe it will take a bit more time to turn it and drive it backwards, but the benefit is that the vehicles can leave quicker. Another option for the vehicles to move quicker is give them the convenience to make a direct U-turn on the Island. However, this has not been realized, because it will take up a lot of space on the Island due to the turning circle, especially of the fire truck.

The vehicles can drive entirely on to the Island and come in contact with risky components. The chance of impact must be excluded, impact on one of the components can lead to disastrous damage. Therefore collision protection in form of steel poles, are placed where the vehicle can come in contact with the components.

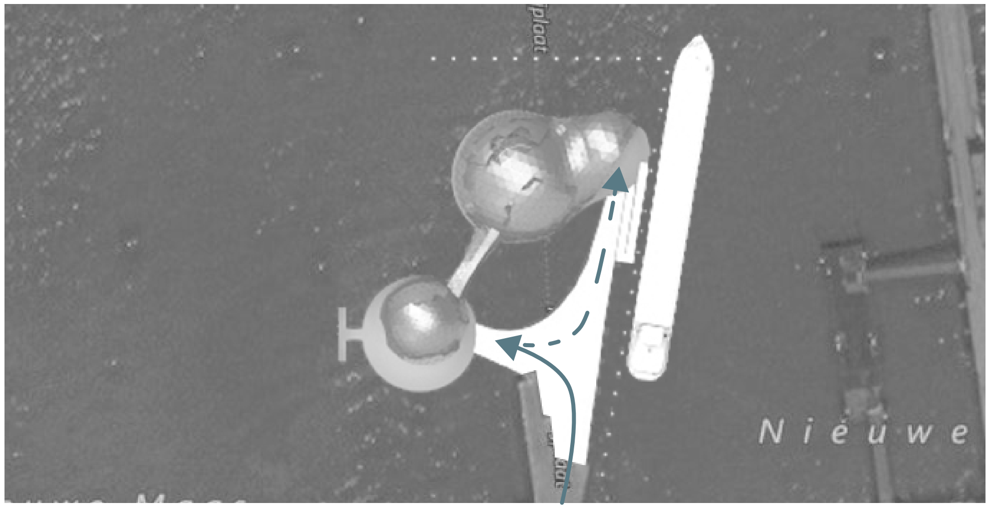
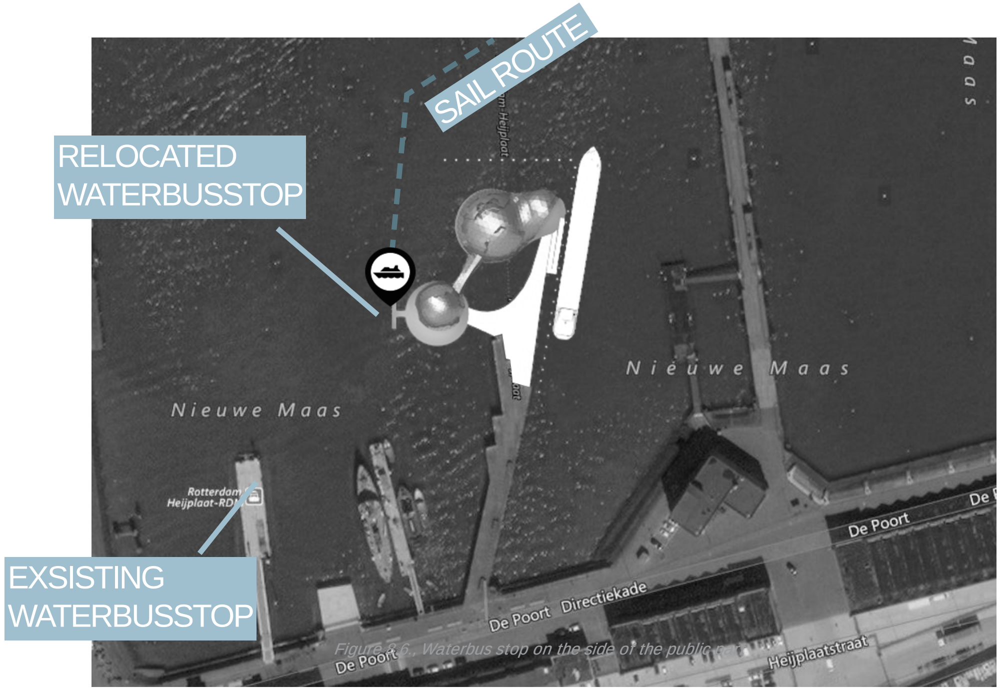


Figure 8.5., Turning principle at the dock and collision protection

The current waterbus stop is, showing in figure x, is relocated to the Island on the Westside of the public. The waterbus and water taxi will sail with a distance from the Island to the stop. The stop is located on the side of the public part, so there is no direct contact with the hydrogen system. If an accident occur they are shielded by the building itself. From the stop the people can walk around or through the building to reach their destination on RDM. Same applies for people leaving the RDM terrain.



8.4 Social impact

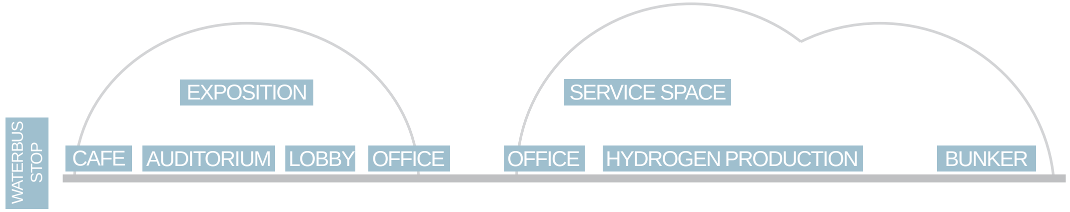


Figure 8.7., Schematic section of the functions

The schools and the companies that are located here, form an creative and innovative hub, that have gained international interest. This area is a perfect location and incubator for the creative and innovative energy carriers, like promoting hydrogen not only for Inland ships, but also for the public. The form of marketing of hydrogen is done in form of architecture, all off the surrounding are built in the 1900 and all have a static image. To obtain more attraction of people, the Island have a complete opposite image than the surrounding buildings. The form is dynamic, inspired and represents “water splitting”. The principle is that there are three molecules one H-atom and two O-atoms. The H-atom represents the hydrogen production and storage, the O-atom that is almost entirely connected to H-atom represents the bunker function and the second O-atom that is almost loose, the furthest from the H-atom, is the public part. However, the surrounding buildings still have to be taken into account and the view of the area should be minimal interrupted by the Island. Therefore the Island dimensions are as compact as possible and the height is only 9,5m at the highest point of the building. The Island is on the water level, which makes it even lower compared to the surrounding buildings. Additionally, the facade with the solar panels are mostly visible from the south side, that are integrated in the facade, will give a bit of an image of sustainability.

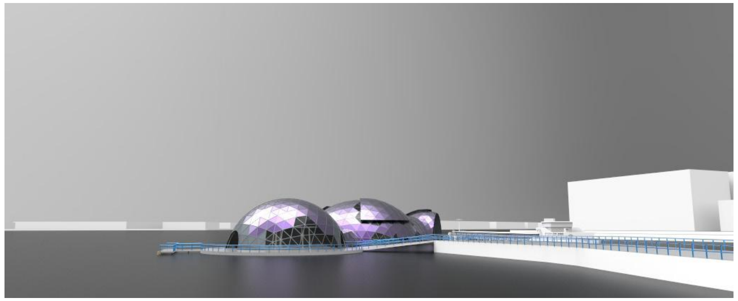


Figure 8.8 , Side view of the Island with the surrounding buildings

The form of education that have a great influence on the acceptance of hydrogen can be given in different methods on the Island. On the ground floor is an exhibition situated for the public where they can easily walk through, especially when they arrive by the waterbus, if they get more interested they can go to the first floor where there is a larger exhibition and if not, they can continue their on way to the exit to the RDM. In these exhibition all kinds of new technology and innovative solution, not only of hydrogen are displayed. There is also a room available for workshops or presentations in de auditorium. This gives the possibility to have more specific demonstrations about certain topics.

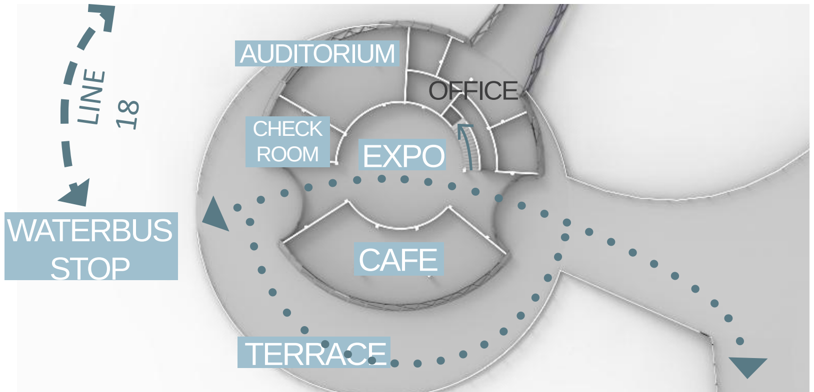


Figure 8.9 , Floorplan of the public functions

It is a bit difficult to expose the product (hydrogen system) to the public, because of safety reasons, guided tours are not a option. However, the form of exposing for the public is done visually. In the exhibition the whole system of the Island will be explained and the exhibition most of the hydrogen system is visible, it is even better visible when the person the travelling by the waterbus. The hydrogen system runs mostly on the North facade and it is transparent when there is a essential hydrogen component on the inside.
However, for the interested Inland ship companies it is direct exposure to the product. In the problem statement is discussed that the ships have to significantly lower their CO2 and sailing by hydrogen is a promising option. What is happening at the moment is that the companies will not build or convert any Inland ships that can sail on hydrogen, because of the fact there is no opportunity for bunkering hydrogen. They are waiting for someone to take initiative that can provide hydrogen and companies that can provide hydrogen are waiting for the Inland ship companies to provide the ships. By showing an realizing this Island, exposing the product, will be a trigger to start the companies to convert the current ships into hydrogen ships.

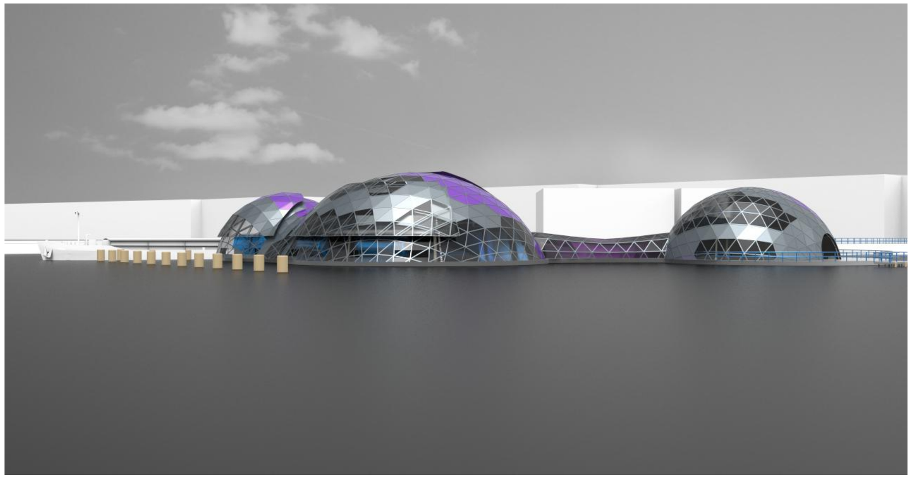
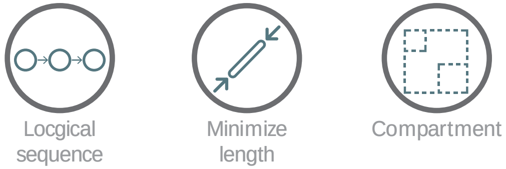


Figure 8.10 , View from the waterbus to the hydrogen system

8.5 Functionality



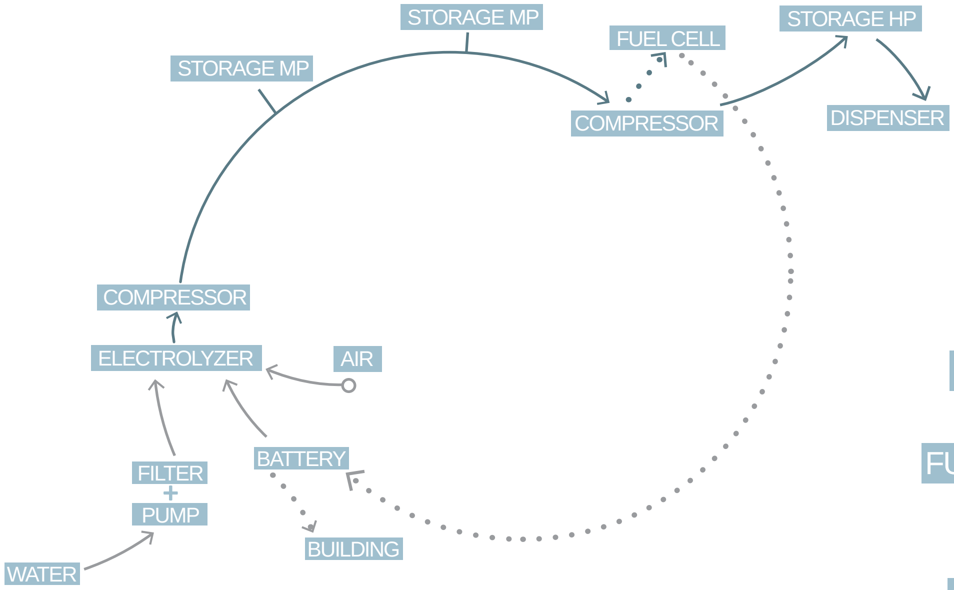


Figure 8.11 , Hydrogen system of the Island schematic

Above the schematic energy scheme is shown how the energy system is implemented in the Island. In the requirements is described that it should be designed in a logical sequence, so that there will be no unnecessarily long pipes, which will reduce the risk of damaging the pipes. The electrolyser is fed with the water from the Nieuwe Maas through the pump and filter and the electricity is generated from the solar panels, if there is abundance and from the rest from the green electricity grid. The air handling units are located on the second floor which supplies the air for the electrolyser. This is compressed to 50 bar and runs to the North side of the Island to the middle pressure storage. If the electricity generated by the solar panels is insufficient the hydrogen can be converted into electricity through the fuel cells and will run back to the battery and power the building. Most of the hydrogen will be compressed to 350 bar and will be bunkered onto the ship by a dispenser.

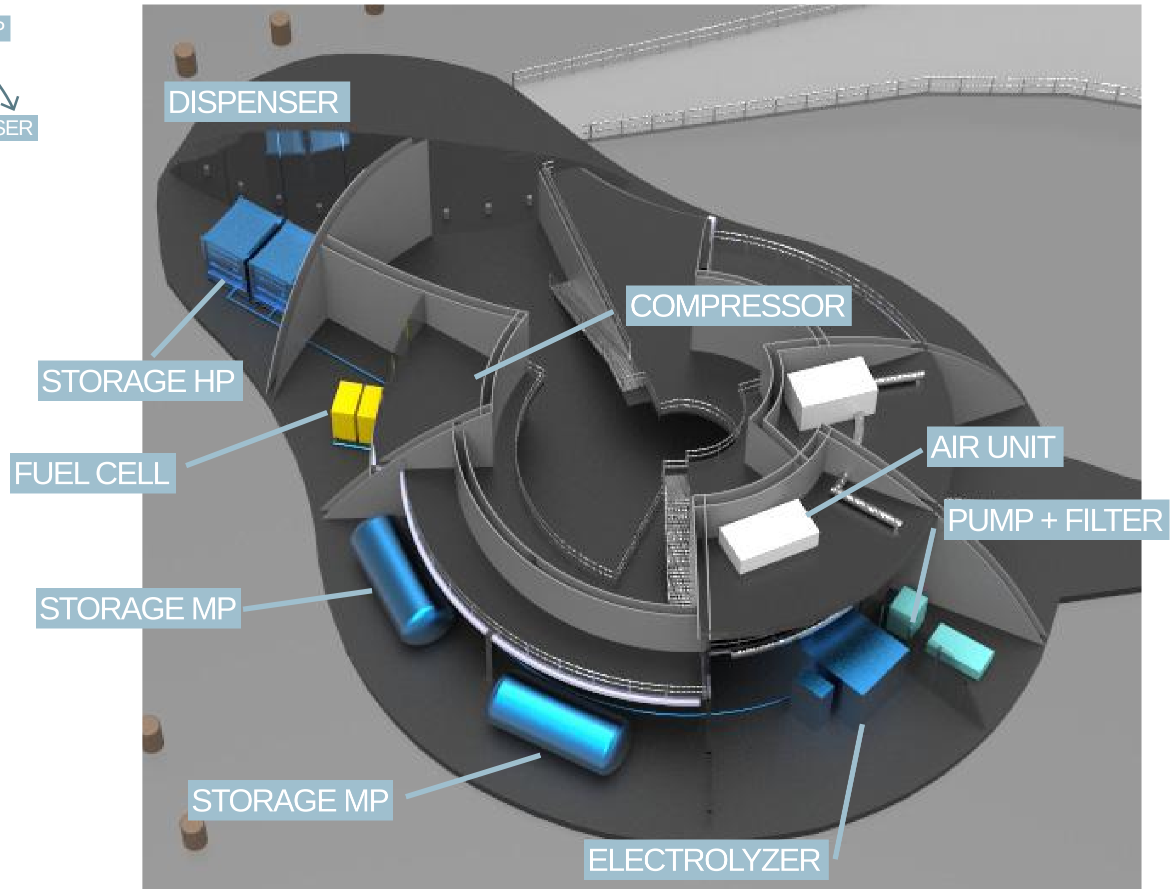


Figure 8.12 , Hydrogen system final

The whole hydrogen system is be located in the North part of the Island. The components are situated next to each other creating a “controlled risk zone”. The pipes run through that space, so no tripping or impact damage can be caused on the pipes. Each components is situated in a compartment to minimize the effect of an incident in one space and limit the damage to other components.

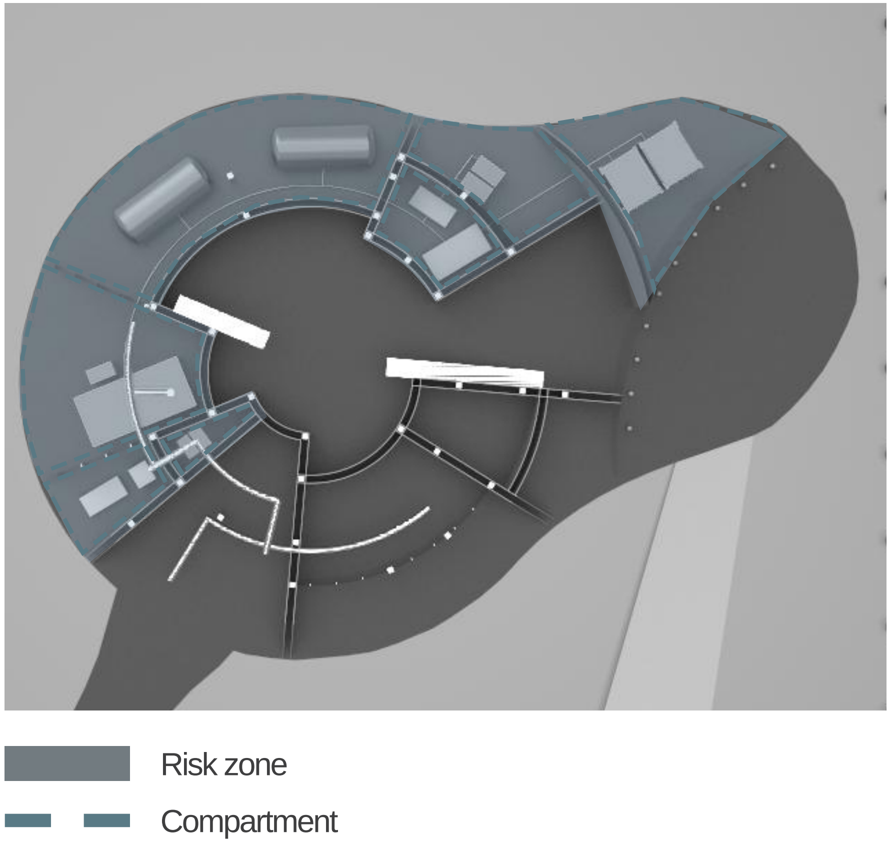


Figure 8.13 , Hydrogen system compartment and riskzone

8.6 Accumulation prevention

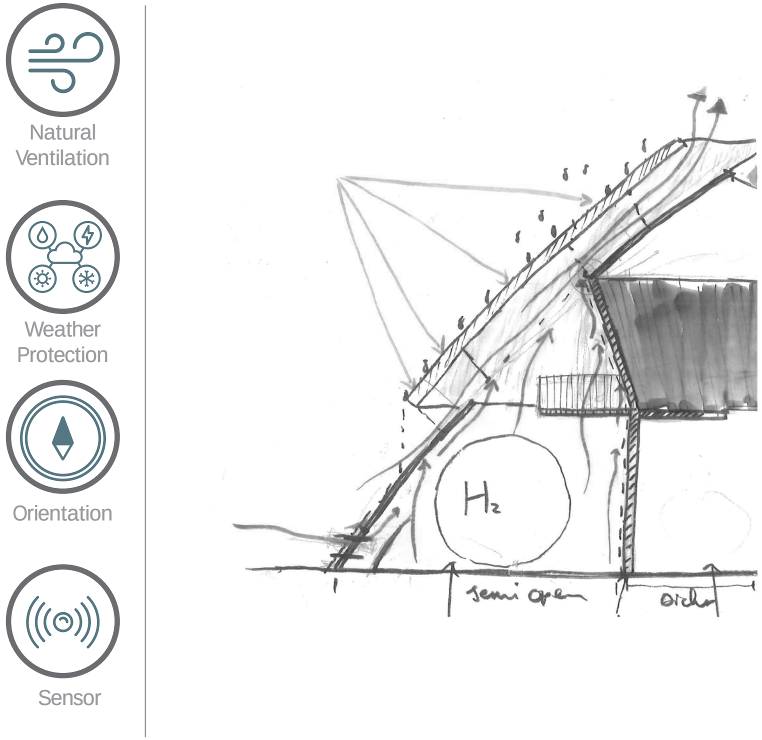


Figure 8.14 , Sketch ventilation principle

The avoid any possible accumulation of hydrogen and assist the hydrogen escape away in case of an unexpected release, a venturi effect principle have been applied. The cool fresh air from outdoors flows into the building through the openings in the facade near the ground floor. The second cover, will heat up the air in the space between the cover and the building. The heated up air is lighter than the fresh air, will rise and exit to the opening in the ceiling, the heated up air will pull the fresh air from the outside into the building. Additionally, the Island is located in an open space where there is little hinder to the wind, which supports the natural ventilation of the spaces. By adding this intervention will prevent hydrogen accumulation in a simple and cost effective way and much more reliable than mechanical ventilation.

At the same time it helps to keep the temperature under control to prevent overheating.
Additionally, the cover will also provide weather protection, it protects the hydrogen storage from direct sunlight, which also support avoiding of overheating of the hydrogen storage. The cover will keep the hydrogen storage mostly dry, even though the hydrogen storage are resistant to water. Keep them mostly dry, will prevent possible corrosion problems and keep the space clean so less maintenance is required.

The possible leakage will be guided through an opening in the ceiling, this controlled guidance will make sure that if there is a leakage of hydrogen it can only go through this opening, therefore hydrogen sensor will be located in this opening. These gas detectors, will detect the presence of hydrogen, it can detect if there is 0.4-4% hydrogen in the air and it can perform under ambient temperatures from -20^{o}C to 80^{o}C and under relative humidity 5% to 95%, therefore it is very suitable for outdoor environment.

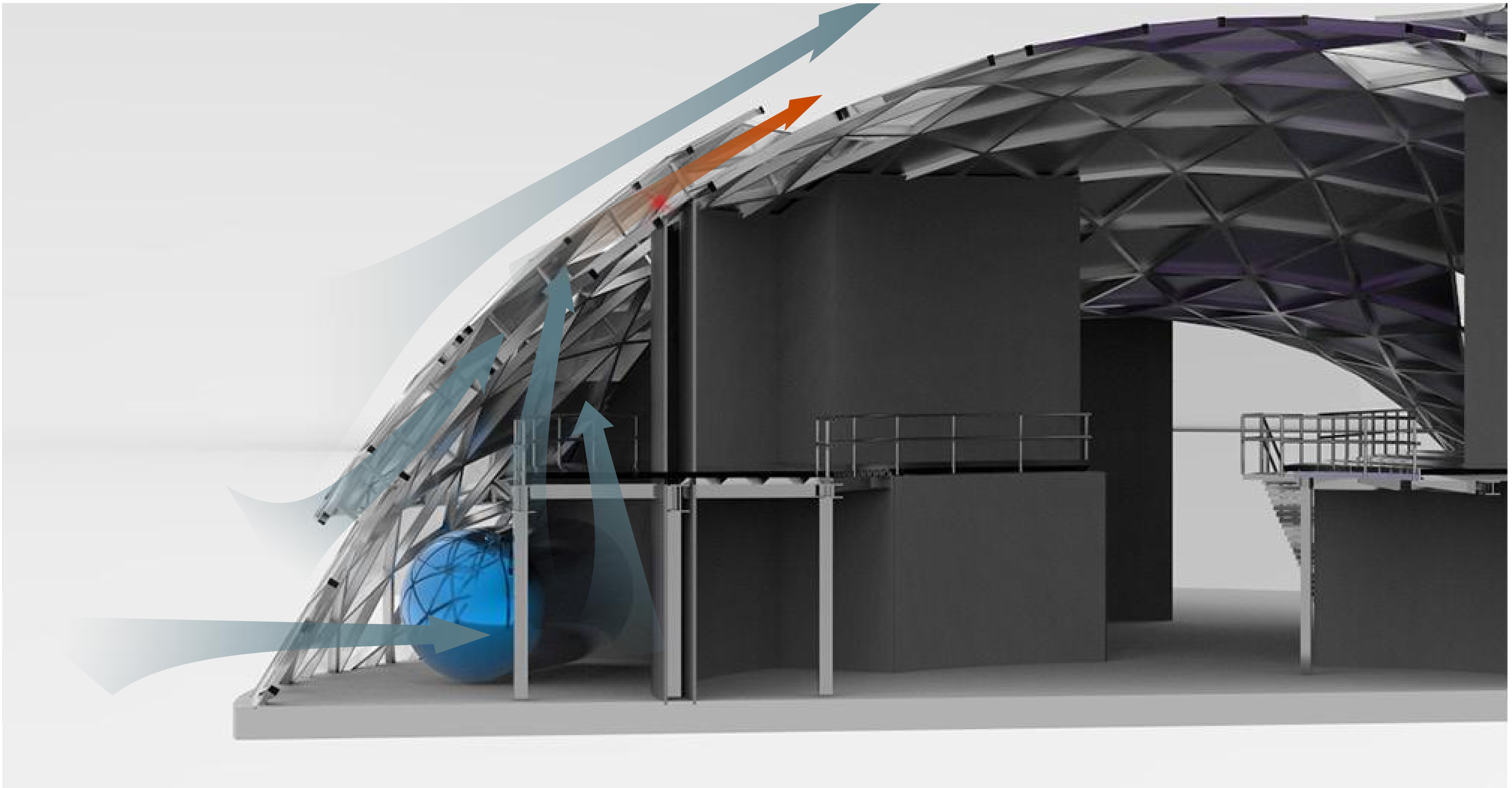


Figure 8.15 , Venturi effect implemented in the building

8.7 Maintenance

Replacement Inspection

The hydrogen system can be visually checked from the same level, but also from above. This done by a split level that runs above the hydrogen storage and the electrolyser. This is easy accesible by the stairs and there is enough height for the employee to walk comfortably. The air intake units are placed on the second floor, these are also easy accesible by the stairs. However, it is not neccessary to check these from above. The heavy and large systems are all placed on the ground floor, in case of replacement it is a lot more functional and easier to transport the components. There is sufficient space in the floorplan for the componets to be replaced. The air handling units on the second floor have to (re-)placed with a forklift truck.

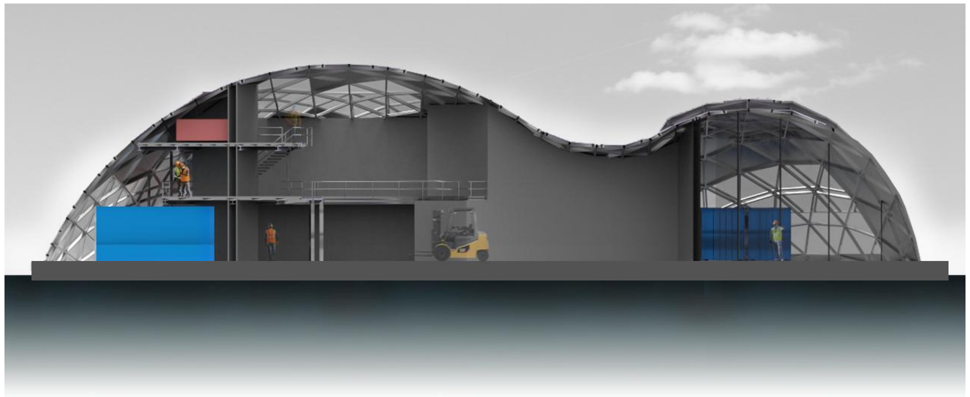


Figure 8.16 , Section of the building where the maintenance is shown

8.8 Acoustics

Isolation

The compressor that compress the hydrogen from 50 bar to 350 bar will produce a lot of noise. The surrounding buildings and people working on the Island should not be affected by the generated noise. Therefore the compressor is placed not directly to facade, like the other hydrogen systems, but in an isolated space. The walls surrounding the compressor are covered with acoustic insulation. The air for the compressor is taken from the semi-open storage space. To prevent contact noise through the floor the compressor is disconnected from the floor through two anti- vibration mats with a floor slab in between.

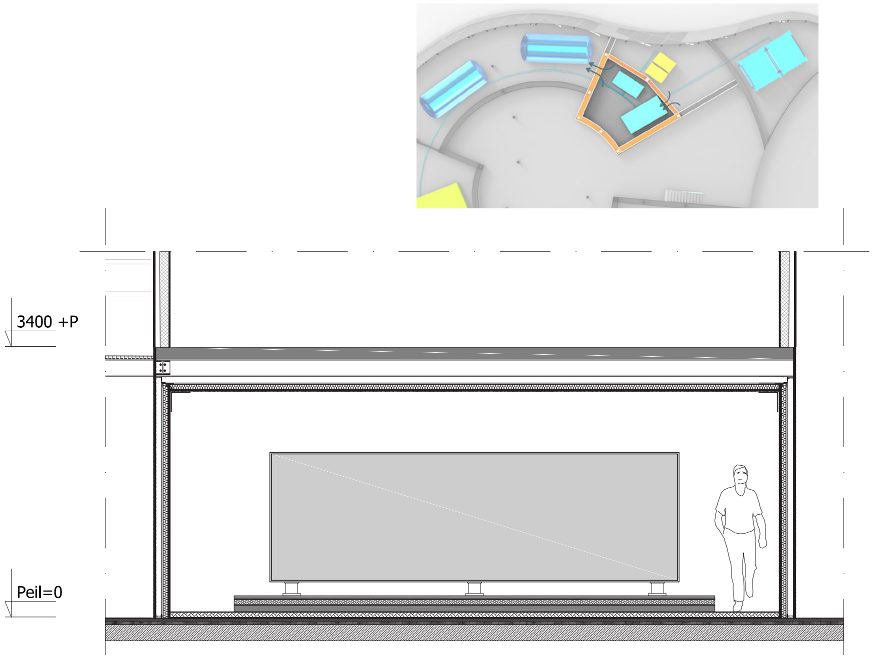


Figure 8.17 , Plan and section of isolated compressor space

8.9 Structure/form

Efficient/ Lightweight | Fire Resistant | Interesting

Earlier mentioned the form is in inspired and represents “water splitting”. The principle is that there are three molecules one H-atom and two O-atoms. The H-atom represents the hydrogen production and storage, the O-atom that is almost entirely connected to H-atom represents the bunker function and the second O-atom that is almost loose, the furthest from the H-atom is the public part. One of the characteristic of hydrogen is that is very light and diffuse. A grid shell as a structure is a perfect typology that represents these characteristics

What is a grid shell?
A grid shell can be defined as a shell-shaped form followed by a grid. The grid, fabricated out of beams, shapes an generally uniformly spaced raster of, diamonds squares, triangles or other less usual surface geometries. Whereby the geometry of the suggested shape and spacing of the grid define the accuracy of estimation of the defined form.

Why grid shell
In general, (grid)shell structures have a elegant and efficient way in spanning large areas with a minimal use of material. The load bearing capability are obtained from the double curvature, hereby membrane action is provided. Meaning that a dispersed load on a (grid)shell will only lead to the build-up of in-plane shear and normal stresses. Commonly bending stresses can be ignored and the stress field will be uniformly distributed over the cross section. Outcome of these effect results in a very efficient structure. (Hoefakker & Blaauwendraad, 2005).

Design of grid shell
Double curved grid shells are efficient structures and the main goal is to reduce the weight of the structure as much as possible, as the dead load is a large proportion of the complete load on the structure.
(Grid)shells are not typical structures with complicated geometries, the approach of designing is different compared to the more usual structures. The approach of grid shells have changed a lot over the years.

Classic approach: Form finding by physical models
The catenary model, hanging a cable or chain or hanging fabric models are straightforward approaches to obtain an optimized form for a shell surface. The chain is not able to resist compression, bending moments and shear forces, it will form a the funicular geometry, the only forces that are present are tension forces. With this characteristic of a chain a net can be created, which results in a three-dimensional supporting model. Only loaded by its own dead weight, the net will form in a spatial curved surface. The inverted form can be achieved, when the geometry is flipped over the horizontal axis. Now entirely axial compression will occur in the structure and still loaded by its own dead weight. It important to note that the obtained form applies to a particular load case. The main objective is to find a form that is sufficient to all other load cases (J. Hennicke, J. Matsushita and F. Otto, 1974).

Modern approach: Form finding by computer software
At the present moment computer software have been developed to make it possible to use it as a form finding tool and calculation as well. On the basis of a approach developed by Ritz in 1909, Richard Courant, a mathematician have developed in 1943 the finite-element analysis (FEA) method. Since 1970, FEA software started to expanse extensively as the computers are capable to solve the large volume of computations. Nowadays, FEA method is the most extensively used method for engineering analysis at the moment (E. Barkanov, 2001). With the help of the computer and software possibilities, form finding with chain models are no longer necessary. FEA programs make it possible to perform form-finding and the structural analysis in the same environment which lead to a much more faster and efficient design tool (M. Bechtold, 2008). This development established the opportunity to create non-funicular structures, compared to physical models where funicular forms where only possible.

Form finding proces
The initial form started from 3 circles, thereof two connected to each (hydrogen production and bunkering) other and one entirely loose (public). The structure is obtained by “draping” a grid over these initial forms. To be sure that the grid completely covers the initial form,

the grid should be defined that exceeds the minimum required are for the form. This method is chosen because of achieving different forms. Below figure 8.18 a schematic principle is shown of the draping method.

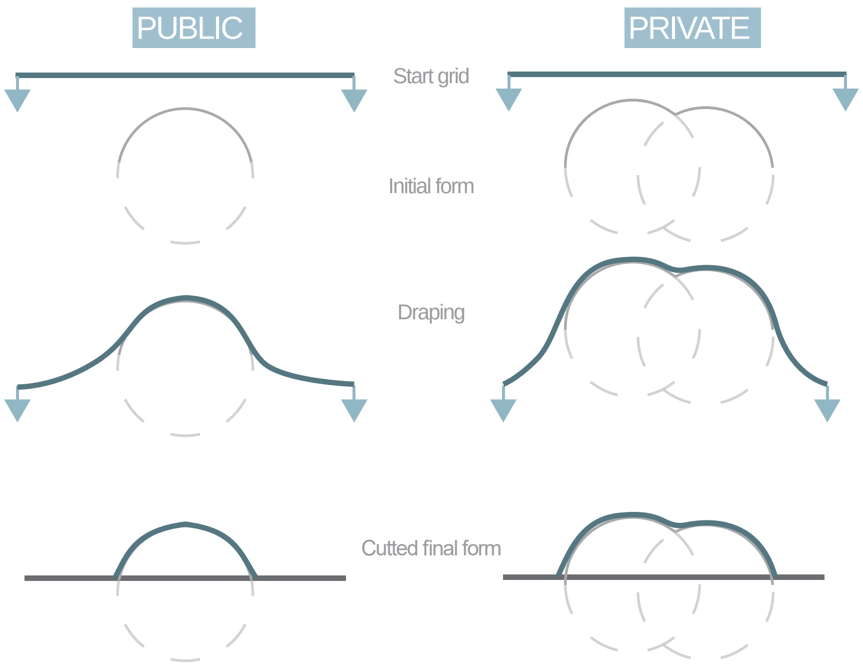


Figure 8.18 , Form finding principle by draping over the grid over the initial form

Kangaroo implementation
The simulation of draping is developed in Rhinoceros and Grasshopper with Kangaroo Physics. The two circles are connected to each other to create one surface. Two types of grids are created in the following way, mesh is made from the square surface divided into a grid of squares and the grid is rotated with 45 degrees second type is the triangular mesh. These grids are draped over the initial form by using the components of Grasshopper Kangaroo Physics 2. Which resulted the excess grid which will be “cut-off”. This same method is applied to the public circle.

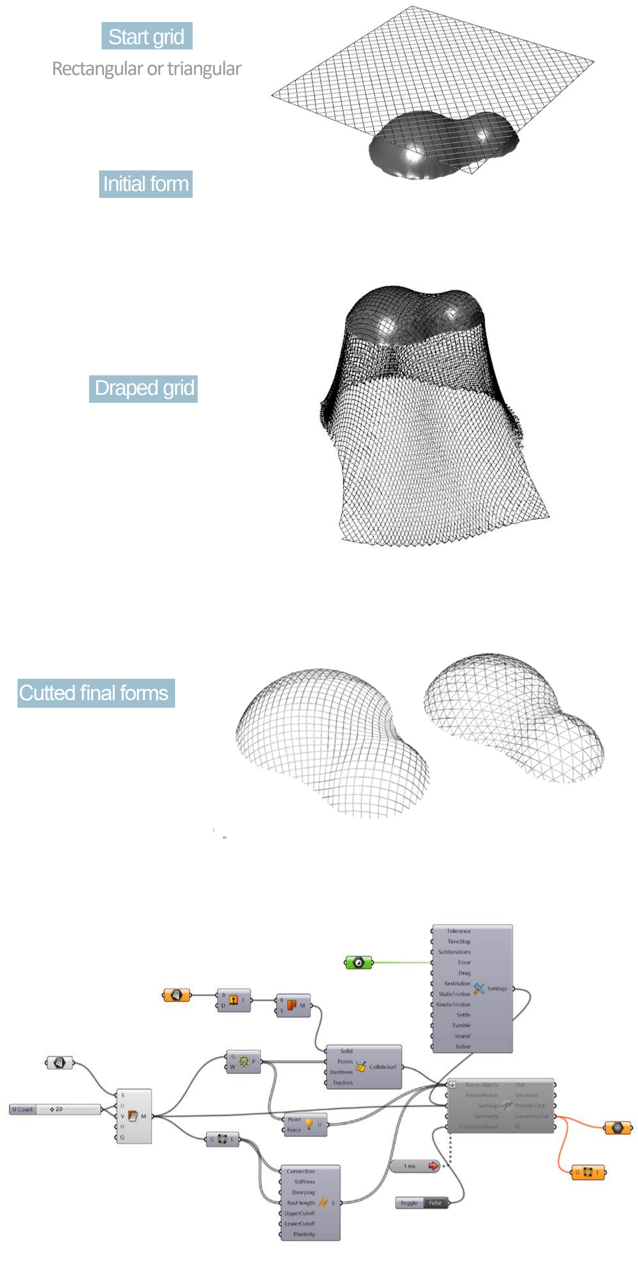


Figure 8.19 , Steps form finding principle by kangaroo

Bunkering ships will take place in a semi opened space. The opening should be fluent as the form and part of the structure. The opening of this space is created by deleting parts of grid. The rectangular grid shell has a more support a the fluent form better than the triangular grid. However, the rectangular grid is quite uncommon and from a structural point of view not that convenient, due to the stability of the rectangles. To find out if the rectangular gridshell is suitable analysis of exsisting buildings is required.

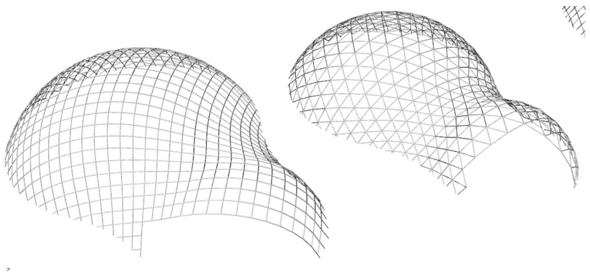


Figure 8.20 , Option rectangular and triangular grid

Exisiting Rectangular Gridshell structure

The gridshell structure is a typology that is getting more popular in the architecure. However, a rectangular steel grid is more uncommon. Therefore a lot of information that can be gained by analysing similar gridshells that already have been realized. Below the following comparable gridshell structures is analysed, these are Hudson Park subway canopy (2015) by Toshiko Mori Architects and Chadstone shopping centre (2016) by CallisonRTKL and The Bucham Group.

Hudson Park Subway Canpoy (2015) by Toshiko Mori
The Hudson Park canopy, located in New York, offers a particular objective to convert a practical cover into a structure that fits landscape and context. The canopy make use of an efficient gridshell that covers the whole entrance. A double curved gridshell with a free form edge beams are supported on supports on the ground floor. The structure is built out of the stainless steel type 2205, which provides strength and durability and the glass panels that are placed are cold-bended. The gridshell is supported with deeper elements in specific axes to be able to hang the lighting (Shlaich Bergermann Partner, 2015). This well thought structure, where the form is the structural support system. Through efficient use of material, the shell creates a lightweight transparent canopy, permitting uninterrupted visual connections across the park (Toshiko Mori Architect, 2015). On the right an axonometric exploded view of the assembly of the gridshell structure.

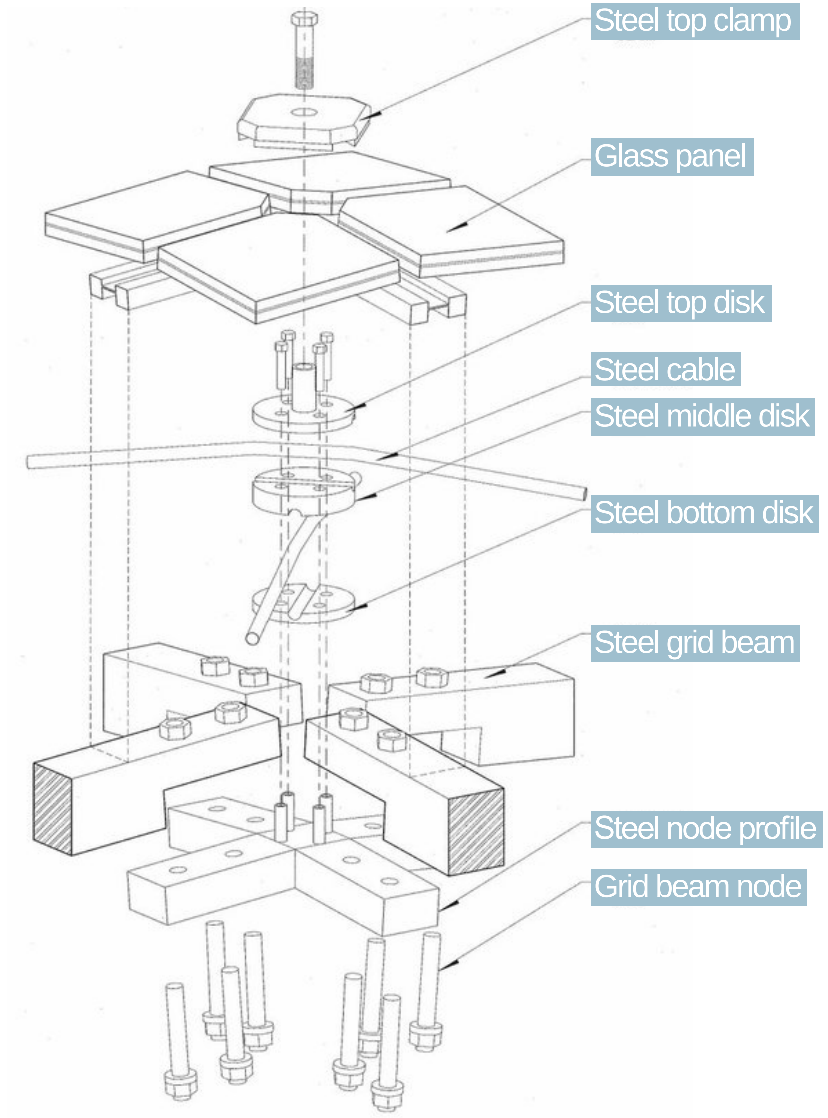


*Figure 8.29. Gridshell structure assembly by Toshiko Mori archtects, Retrieved may **18**, **2018**, from http://www.studiotjoa.com/34th-street-canopy/*

Chadstone shopping centre (2016) by CallisonRTKL and The Bucham Group.
The Chadstone shopping centre located in Melbourne, with a 31 meter height and a span of 44 meter. Due to the cramped planning and the uncertain weather conditions and the local requirements in regard to the operation circumstances on site, requires for an exact logistics approach. Seele (2016) have developed an intelligent solution for the glazed steel gridshell structure, the structure segments were preassembled to a large extent under better and flexible working conditions at a different location. In the perfect coordinated operations, the structure segments, with dimensions up to 18 by 4,5 meter, were transported to the building site. The segments were lifted, piece by piece, into place and fixed. Interruptions caused by harsh weather conditions, that frequently occur in this area, are prevented, due to the quick operations. After placing the strucutre the cold bend glass panels are placed.

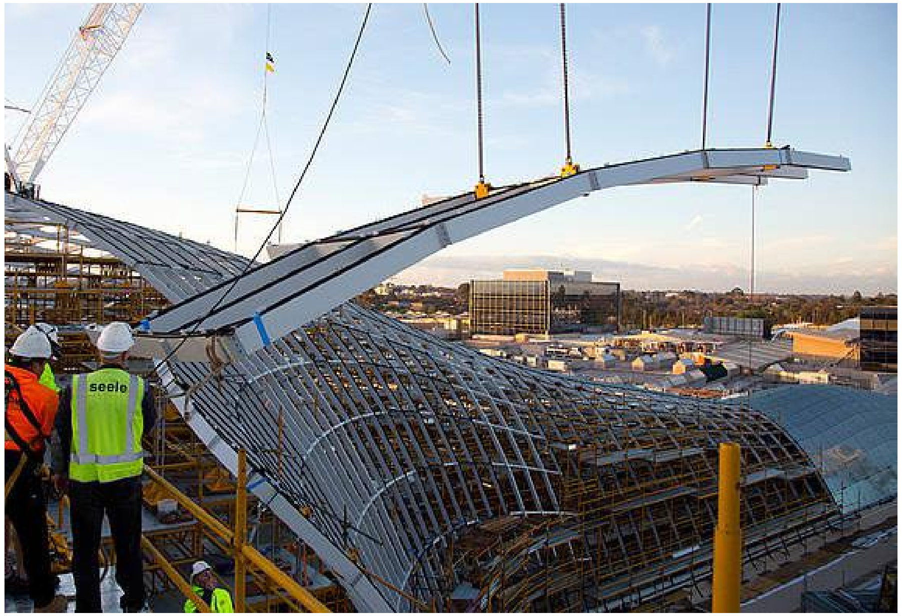


*Figure 8.30. Segtments assembly of Chadstone shopping centre , Retrieved may **18**, **2018**, from https://seele.com/references/chadstone-shopping-centre/*

By analysing existing rectangular grishells, the conclusion can be made that there are a lot more complications that need to be dealt with. For, example, a rectangular gridshell is not stable enough, so therefore additional crosses have to be applied, which is not needed by a rectangular gridshell. The main disadvantage is that the panels have to be double curved in order to fit the structure. This will lead to high construction costs due to the bending of the glass panels. Additionally, the initial idea is to integrate solar panels on the facade, however if the panels have to curved that will lead to limitations of the solar panels, resulting in a low efficiency. The rectangular gridshell will give a lot of complications compared to the triangular gridshell and therefore the triangular gridshell is chosen.

Material choice

The decision making is limited to three materials; wood, aluminium and steel, current grid shells that are realized are constructed with these materials. To obtain the most suitable material for the Island, the material choice is based on three categories Grid shell material values, construction values and environmental values. From this comparison a material is chosen and will be further elaborated. Below, the values will be explained and rated based on CES Edu pack (2016).

Grid shell material values
1. Stiffness, ensuring that the grid shell maintains its form, the material must provide sufficient stiffness
2. Creep, the material of the grid shell are exposed to a constant load, to prevent material deformation over time, a material with the least amount of creep is preferred.

Environmental values
1. Fire resistance, with hydrogen production and storage on the Island, if a fire occurs, direct collapsing of the structure should be prevented. Therefore it is important that the material is fire-resistant.
2. Moisture resistance, due to the surrounding water and rain, the structure is almost always in contact with moisture. To keep the structures integrity, the material must be moist-resistant.
3. UV resistance, The ability to preserve the material performance without deteriorating reaction from direct sunlight.
4. Maintenance, the durability of the material and the amount of maintenance required.

Construction values
1. Erection efficiency, this value is based on the material’s ability to erect during the construction of the grid shell.
2. Connection efficiency, in consideration of the grid shell beams and their ability to connect with each other to construct the overall geometry. Comparison is made of the different methods to connect the components.
3. Costs, each material have different production costs and some require additional costs for delivery

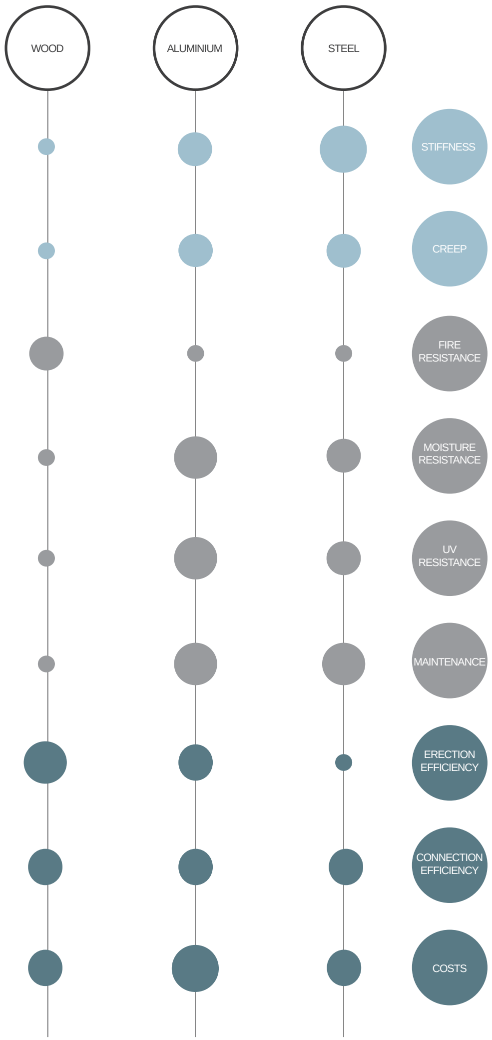


Figure 8.21, Material selection based on Ces Edupack (2016)

The final choice is steel, because of the structural properties, construction abilities and durability of the material. One imporant drawback is that the material is not fire-resistant. Therefore during the detailing the structure must be protected from the fire.

Fire safety

Due to the risks of hydrogen systems the structures have to be well protected from the potential fire. The fire has a major influence to the steel loadbearing structures of the building. That is why it is important that these constructions are protected against fire. For the exterior grid shell structure it would be nice if they are visible. To still ensure the fire resistance an protective coating is applied. However, because of the open parts the coating must be suitable for outside weather conditions without affecting the fire-resistant performance. The weight and the loads of the structure and degree of fire resistance determine the thickness of the coating.

The interior structure does not have to be visible and therefore not necessary to be coated. Instead of coating it will be covered with fire-resistant sheeting. For the reasons that, it is a lot cheaper and better for the environment than the coating.

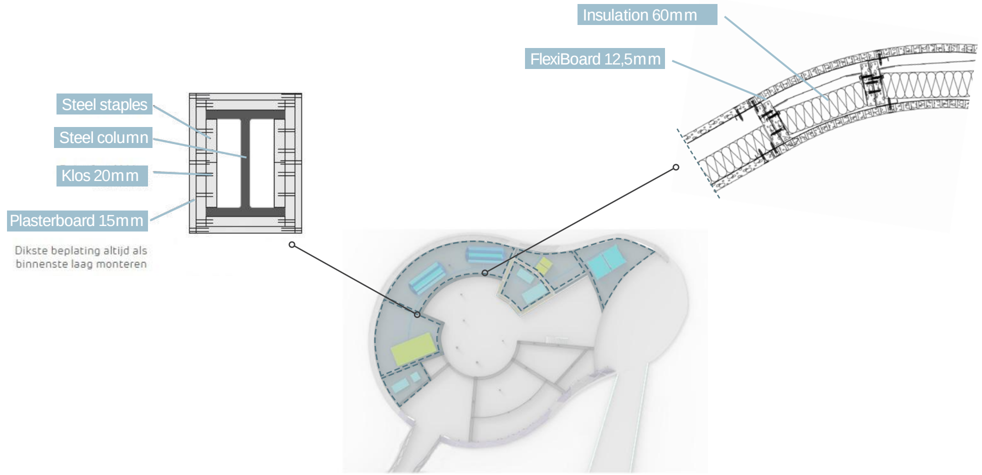


Figure 8.31, Fire saefty interventions structure

Karamba validation

The input for karamaba is based on the triangular grid structure obtained from kangaroo, however there are two openings created by removing members of the structure. The left opening is an entrance for the employees that are coming from the public part. The right large opening is made for bunkering in the open and for services to arrive. The aim of the Karamba analysis is to ensure that there is a minimal displacement with the according cross-sections, only vertical loads will be taken into account, the wind load have been disregarded. The assumed condition of each intersected line and support are fixed in the analysis. The possible loads that are taken into account are the dead load of the structure and 0,7kN/m^2 for the live load. This is placed on each intersection of the grid. The windload points is placed on the largest surface of the facade facing North with a load of 1kn/m^2. For the cross sections are rectangular with a height of 15cm, width of 10cm and a wall thickness of 0,3 cm, together with the material properties of steel S235. The result of this analysis gives maximum displacement of 10mm on the middle curvature of the structure. This displacement is within the boundaries of L/600. The width of the beam is a bit larger than required for the structure. However, on this beam space is needed to mount the facade panels.

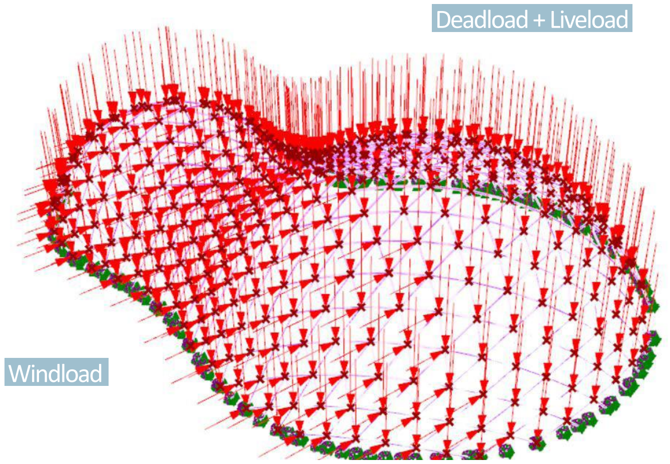


Figure 8.22, Result karamba analysis

Structure system

The structure system consist out of two parts the interior and exterior. The interior is made out of steel columns and beams. To strengthen the fluent form and hydrogen system from the inside, the floors and the some of the inside walls are curved. Due to these curves, some beams must also be curved to enhance this appearance, to reduce the costs only the edge beams of the walls and the floors are curved. The beams that are inbetween the are straight beams that span from column to column.

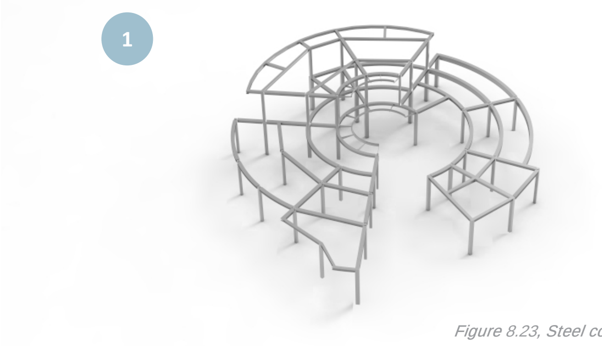


Figure 8.23, Steel columns and beams

With columns and beams connected to each other is not enough to provide stability. The stability is ensured by making two interventions. First, bracings are constructed in the walls that goes from the center to two outside. These are located between the walls, so they will not affect the logistics in anyway.

Figure 8.24 Bracings

The bracing in the walls are not enough to provide stability from all directions, per floor at least three vertical stability planes needed if the floors also act as a horizontal rigid plane. That is why there is chosen to make in connection of the inner circle fixed. There cannot be any bracings on these planes because that would obstruct in case of replacement of a component. Fixed connection between the column and the floor beams are suitable, because the building only have a couple of floors.

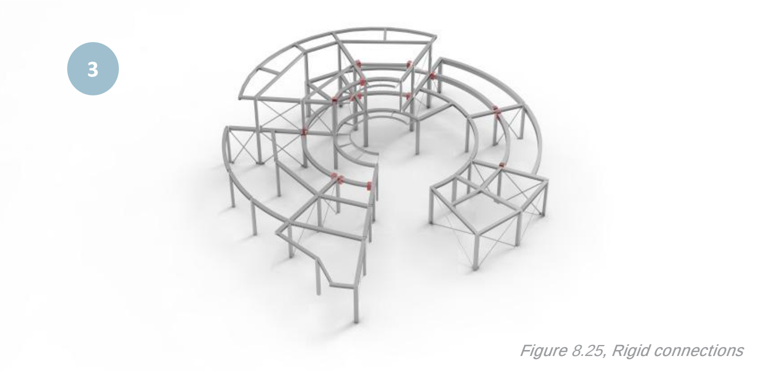


Figure 8.25, Rigid connections

The floors all end with a curvature, making it a bit more difficult to construct. The choice is made to use a composite slab with profiled steel sheeting. Due to the curved ends, the floor have to be cut. Cutting the steel plates is a lot easier than hollow-core slab or wide slab floor. If one of these floors was applied they have to be sawn in the right form, which is a lot more labour-intensive. The floors are spanned from the inner circle to the outside in-between supported by the beams.

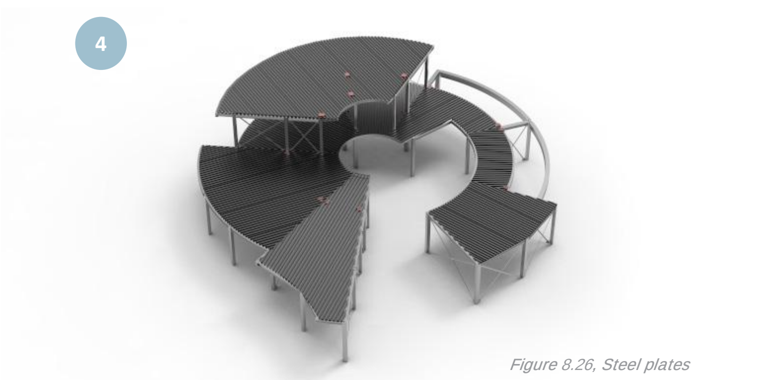


Figure 8.26, Steel plates

The ComFlor 46 developed by Dutch Engineering (2013). If the floor has a total thickness of 100mm it is 60min fire resistant. On the right there is an open space. This is where the hydrogen storage is located, if a closed floor is placed, it will create a chance to let the accumulate. That is why a slatted floor is placed, where the people can walk over and check the hydrogen storage.

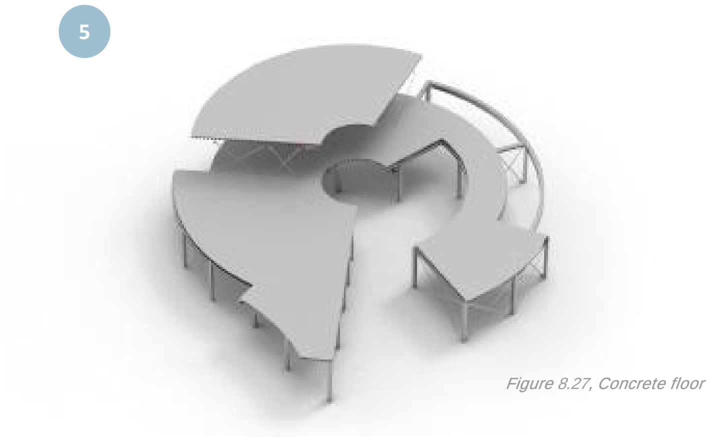


Figure 8.27, Concrete floor

When the interior structure is finished the exterior grid shell is constructed. The gridshell is constructed out of segments, comparable to chadwick shopping centre, resulting in a shorter construction time. When the structure is finished, the panels can be secured.

Figure 8.28, Steel grid with crosses

Facade structure system

After the triangular structure is completed, the facade panels can be placed. First, a wedge is placed on the grid beam, this wedge allows the different panels to be connected on one profile. On top of this wedge a rubber gasket is clamped, allowing the panels to be placed under an angle. On top of the gasket the different panels can be placed, solar, glass or sandwich. These different configurations are shown on the next page in a 2D drawing (scale 1:10). These panels are clamped with the profiles and connected to the threaded bolt that are pre-welded on to the grid beam. Between the profiles and the panels is another rubber gasket ensuring a wind- and watertight seal. At last a steel cover profile with the same finish as the sandwich panel is placed over the bottom profile. An exploded view of the facade system is shown in the figure on the right.

1. Steel grid shell beam
2. Plastic wedge, top rubber gasket
3. Steel sandwich panel
4. HR++ glazing
5. Solar panel
6. Steel underprofile
7. Steel coverprofile

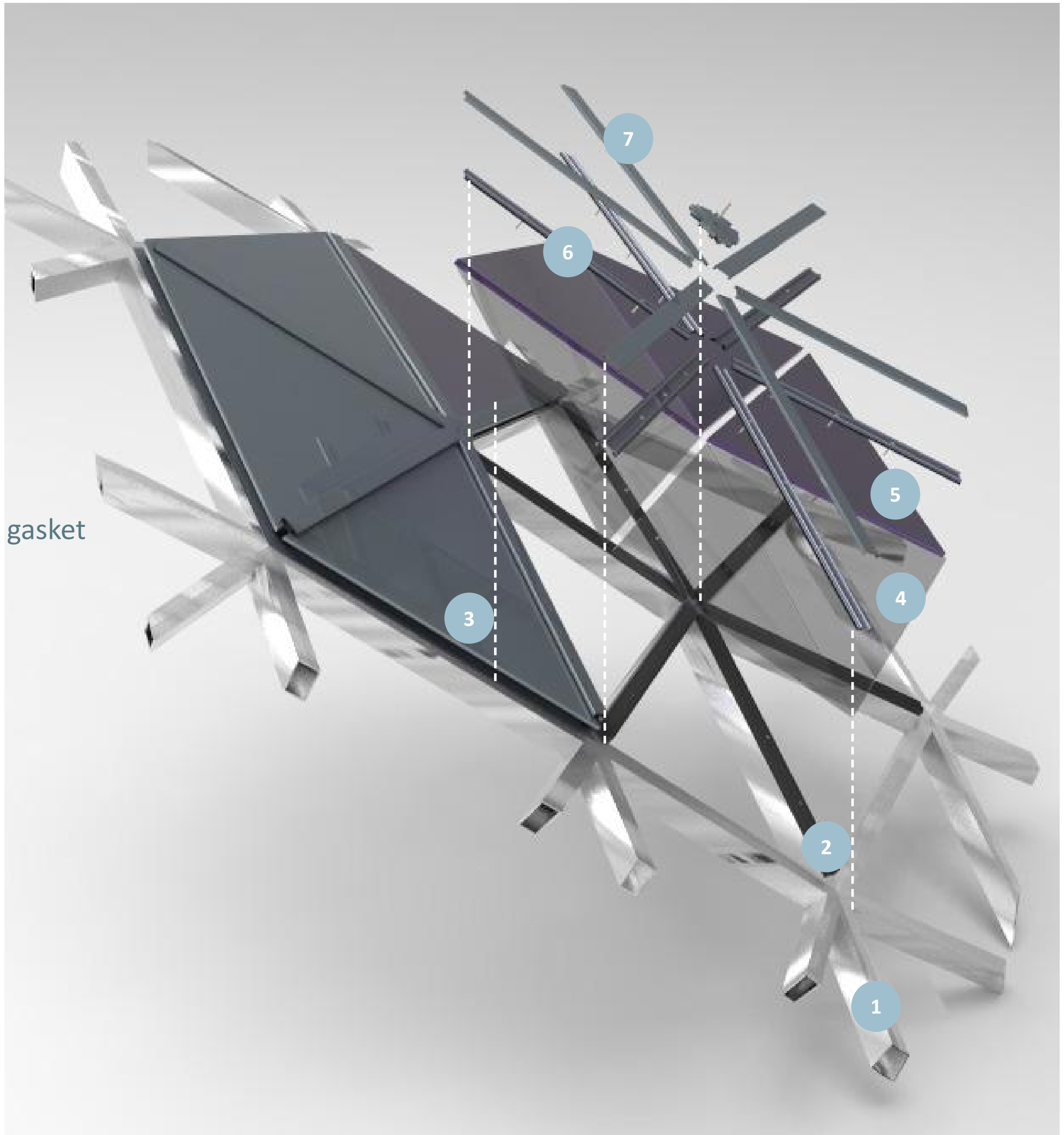
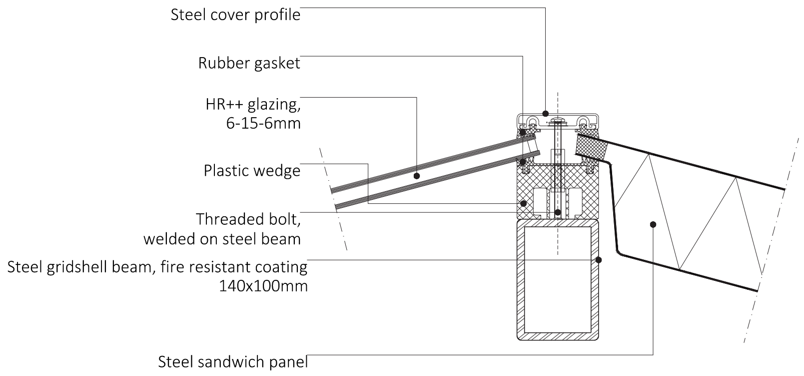


Figure 8.29, Exploded view facade segment

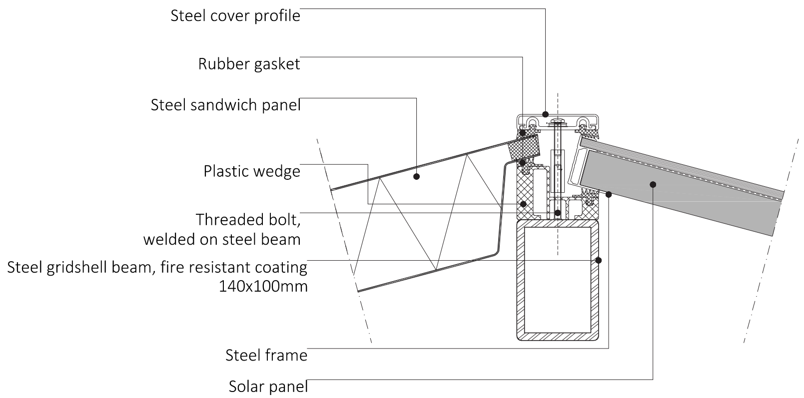
A

HR++ glazing
+
Steel sandwichpanel



B

Steel sandwichpanel
+
Solar panel



C

Solar panel
+
Solar panel

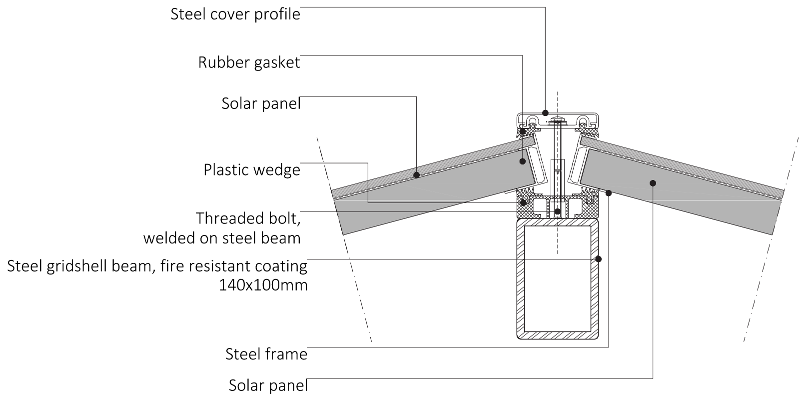


Figure 8.30, Facade configurations

8.10 Energy production

Clean energy   Integration

In the previous chapter a list of requirements for solar panel integration was given. These requirements have been implemented in the design in the following ways. The panel surfaces of the facade are in accordance with the division of the grid shell, which creates the freedom to place different panels on the grid. Due to the grid the panels will be integrated with the structure and naturally following the lines of the design. There are three different facade infills for the building, these are; glass, steel sandwich panel and solar panel. In the image below the North side of the Island is shown, in this image the three different panels are clearly visible. By making the closed panels grey, the three different panels have a good colour composition together.

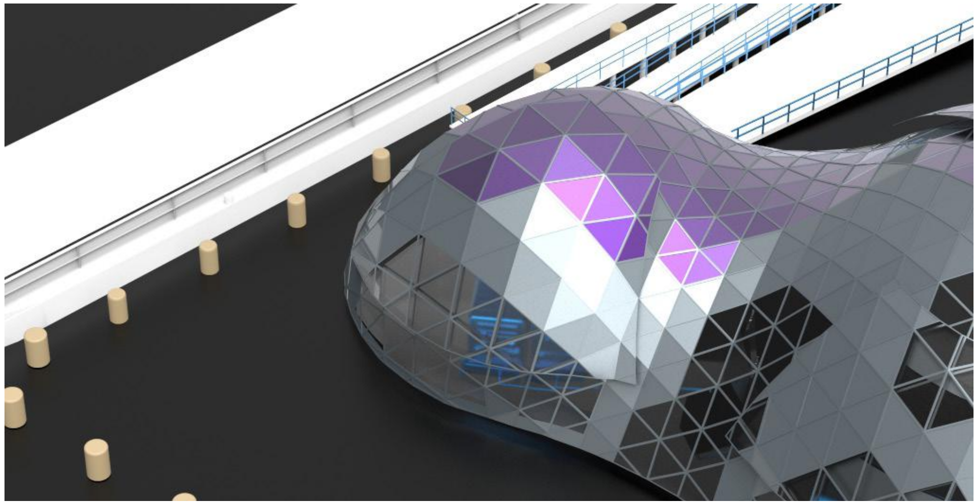


Figure 8.31 Different facade panels

A radiation analysis is made in Ladybug, an environmental plug in for Rhino Grasshopper, developed by Mostapha Sadeghipour Roudasri. Ladybug imports epw format weather files, that are developed by the US Department of Energy. This weather file include data for every hour of the year and contains the following; location information, humidity, temperature and enthalpy, wind and radiation data (Wintour P. ,2016)

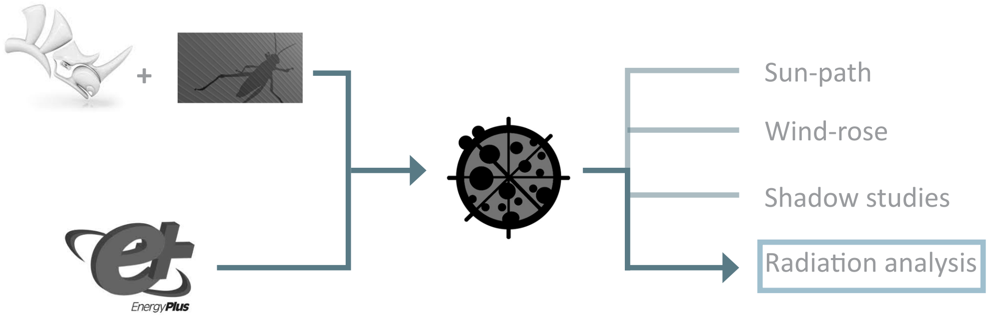


Figure 8.32., Ladybug analysis scheme

The building is orientated in a way where the largest surface is directed to the sun to ensure a most optimized energy generation. This is shown from the results of the Ladybug radiation analysis, the analysis period is a whole year. The orange surface is where the façade most often comes into contact with the sun.

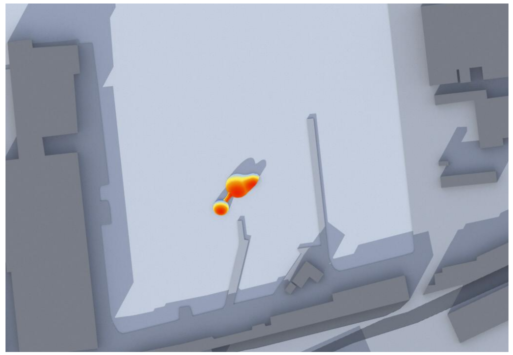


Figure 8.33., Ladybug analysis result

The grid shell allows flexibility in the arrangement of the facade panels. To be able to use full potential of the solar panels, the facade composition is based on the results of the radiation analysis from Ladybug of a year. The positioning of the solar panels are in accordance with the orange surface. However, solar panels cannot be placed on all the orange surfaces, due to the requirement of daylight of functions located behind the facade.

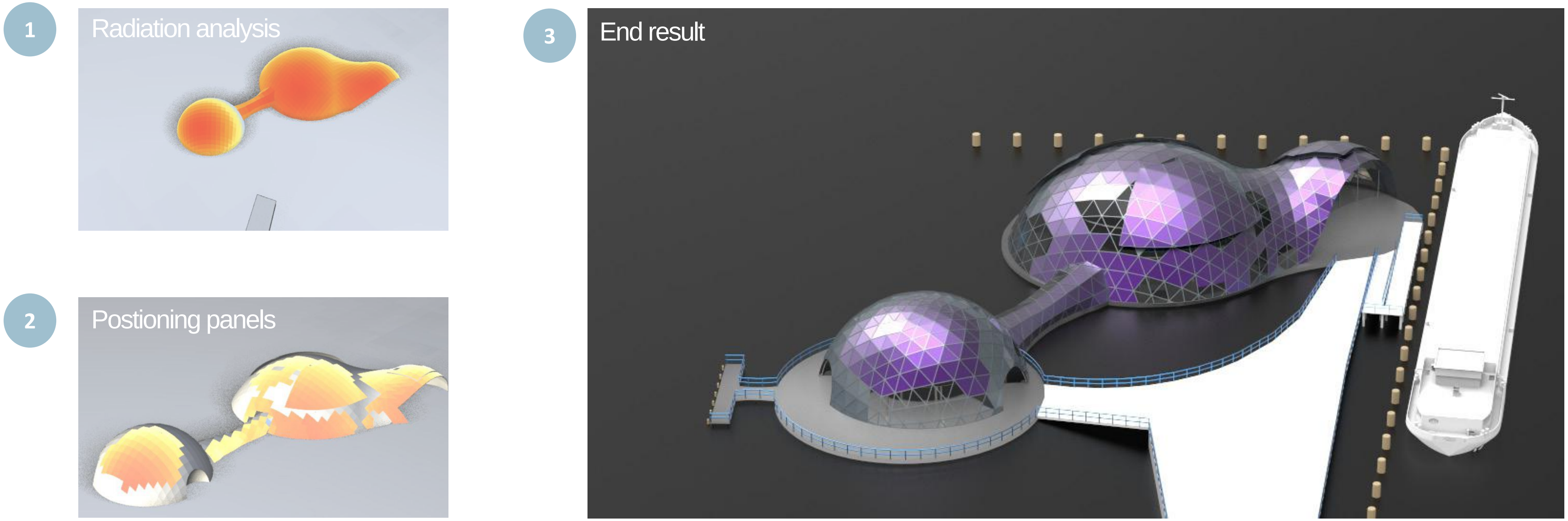


Figure 8.34., Ladybug analysis result converted to solar panels

Chapter 9
Energy production

9.1 Introduction

In this chapter the total energy generation from the solarpanels will be calculated. First, the possible types of solar panels will be layed out and the most suitable type will be chosen. The amount of radiation will be anaylzed in Ladybug and a final calculation will be made for the total energy production of the Island.

9.2 Types of solarpanels

There is a wide range of different solar panels available, each type serve different purposes and demands. The types of solar panels are divided into three classes of generations.

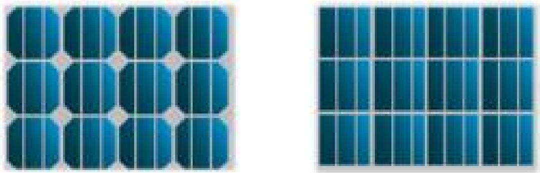


Figure 9.1., Monocrystaline and polysilicon solar panel

First generation
This is the most traditional type compiled of monocrystaline or polysilicon and are typically used in conventional surroundings. The monocrystalline solar panels (Mono-Si) is the purest type, they can be recognized by the uniform dark surface, with rounded corners. This type of solar panel consist of high purity silicon, leading to one of the highest efficiency rate, the most advanced ones reaching above 20%. Most of the mono crystaline have the longest life span, some manufactures give 25-year warranty and they are less sensitive for high temperatures. The production involves The Czochralski process, in this process a considerable amount of silicon is gone to waste. Because of the high purity and production process, the monocrystalline is the most expensive.
Polycrystalline solar panels (p-Si) also belongs to the first generation. These panels can be recognized by the different shades of blue speckled surface with sharp corners. The production is simpler and cost less, compared to the monocrytalline, however they have a lower efficiency rate of roughly 13% tot 16%

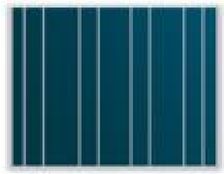


Figure 9.2., Thin film solar panel

Second generation
This generation include different types of thin film solar cells, this is an option that is less expensive. These are manufactured by layering photovoltaic films on top of a substrate. This type of solar panels are easy to produce and less material is required. The thin film are flexible and less senstive to high temperatures. Two drawbacks are that a lot of surface is required and they have a lower durability than the cystralline solar panels.

Third generation
These types of solar panels consist of a variety of thin film technologies, but they are still in development phase. One of these, is the cadmium telluride solar cell,

which empowers relatively low production cost. Production of this type of solar cell require the least amount of water. It is more cost efficient than crystalline silicon panels and reach a efficieny of 21%. However, the major disadvantage is the substance, cadmium telluride, being toxic when it is inhaled or ingested. (Office of Energy Efficiency & renewable Energy)

	Efficiency rate	Advantages	Disadvantages
Mono-Si	~15-22%	- High efficiency - Good durability - Optimised for commercial use	- Expensive
P-Si	~13-17%	- Cost effective - Reduced silicon waste	- Lower efficiency rate - Lower durability
TFSC	~7-13%	- Cheap and easy manufacturing - Not temperature sensitive	- Lowest efficiency rate - Lowest durability

Table 9.1., Advantages and disadvantages of the solar panels

The type of solar panel that is chosen at this moment is the Mono Crystaline. This is a bit more expensive, but it has the highest efficiency and good durability compared to the other types of solar panels. The energy generated by the solar panels is far from enough to produce the required hydrogen and power the building. However, the renewable energy production should be as efficienct as possible.

9.3 Energy generation

The approach of obtaining the amount of radiation on the solar is done in Ladybug analysis. In the chapter final design decisions, an explanation was given that the surfaces which has the most radiation are placed with solar panels, only those are solar panels are only involved in the analysis. The total surface of solar panels are 635m^2 placed on the public and private part of the Island. The total radiation of each month is derived from the Ladybug analysis.

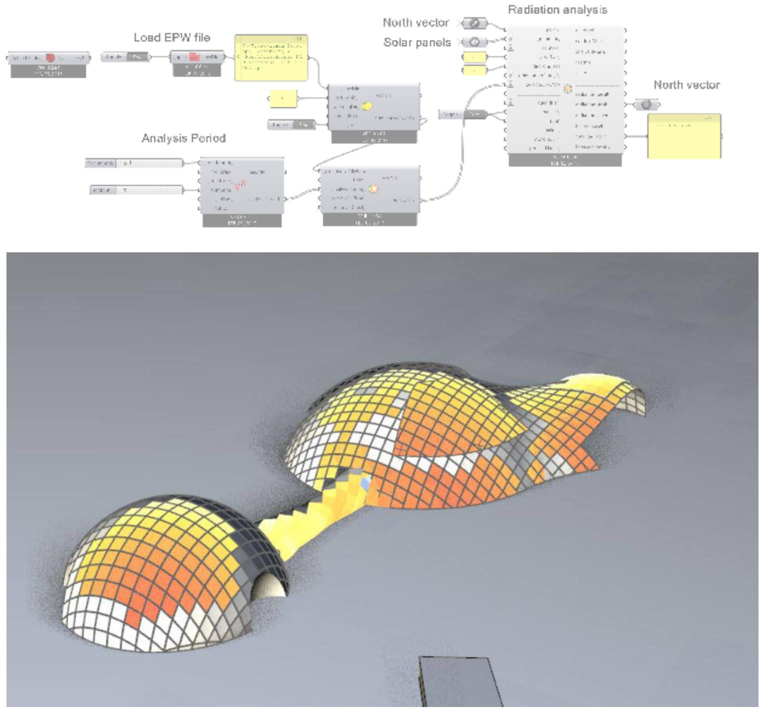


Figure 9.3., Monthly radiation analysis script only solar panels inculded

An efficiency of the monocrystaline solar panels is taken of 20% together with the solar yiel of 0,9. In the table below the radiation of each month of all the solar panels are shown and the generated energy from the monocrystaline solar panels.

Solar energy generation

Month	Radiation kWh	Generated kWh
January	24630	4433
February	44669	8040
March	80716	14529
April	95355	17164
May	130821	23548
June	124877	22478
July	131169	23610
August	113788	20482
September	79901	14382
October	50850	9153
November	29145	5246
December	17416	3135

Table9.2., Total radiation and generation of the solar panels

Chapter 10
Final calculations

10.1 Introduction

This chapter start of with the total energy generation and demand is layed out. In the following sections, the different components are chosen, calculated and the method used is explained.

10.2 Energy summary

In table on the next page the total amount of energy production and demand is shown per month. The total energy demand of for heating and cooling and the appliances for the building is 63 mWh per year. The energy production from the solar panels are explained and calculated in the previous chapter, the total electricity produced by the solar panels is 135 mWh per year. This includes the energy loss of conversion (5%), battery charge (10%) and distribution (5%). Because the waste heat is used that is produced by the electrolyser, it results in a surplus energy of 89 mWh per year. However, to produce the rest amount of hydrogen that is required for the ship, a total of 7406 mWh per year is required only for the electrolyser and 125 mWh per year for the compressors. The electrolyser have a efficiency of around 70%, therefore 30% waste heat is produced. Even with the waste heat used for the building there is still a surplus waste heat of 2223 mWh. This can be stored in seasonal thermal energy storage, however more research is necessary to see what the exact requirements are. The storage also need to be located somewhere off the Island, due to the sufficient space. To be able to compensate for the shortage of a total of 7442 mWh, three wind turbines of 1.2MW with a average of 2190 full load hours is required. In this calculation the fuel cell is not taken into account, because of the high demand of the electrolyser.

SUMMARY PER YEAR			
Heating demand	**-17**	mWh	
Cooling demand	**-3**	mWh	
Appliances	**-43**	mWh	
Total energy use building	**-63**	mWh	
Solar generation	**166**	mWh	
Efficiency	**135**	mWh	
Used waste heat	**17**	mWh	
Surplus solar energy	**89**	mWh	
PEM demand	**-7406**	mWh	
Waste heat PEM	**2240**	mWh	
Surplus waste heat	**2223**	mWh	→ **Seasonal thermal storage**
Compressor PEM-MP	**-3**	mWh	
Compressor MP-HP	**-122**	mWh	
Shortage electricity	**-7442**	mWh	→ **3x 1,2 MW windturbine**

Table10.1, Summary energy production and demand of the Island

	January	February	March	April	May	June	July	August	September	October	November	December
Heating demand	-3891	-2649	-1955	-1890	-562	-23	-10	-4	-439	-564	-2143	-2955
Cooling demand	0	0	-7	0	-384	-800	-768	-597	-73	-62	0	0
Appliances	-3600	-3600	-3600	-3600	-3600	-3600	-3600	-3600	-3600	-3600	-3600	-3600
Total energy use	-7491	-6249	-5562	-5490	-4546	-4423	-4378	-4200	-4111	-4226	-5742	-6555
Solar generation	4433	8040	14529	17164	23548	22478	23610	20482	14382	9153	5246	3135
AC-DC conversion	4211	7638	13803	16306	22371	21354	22430	19458	13663	8695	4984	2978
Battery charge efficiency	3790	6874	12422	14675	20134	19219	20187	17512	12297	7826	4485	2680
Transport storage and distribution	3601	6530	11801	13941	19127	18258	19177	16637	11682	7435	4261	2546
Used waste heat	3891	2649	1955	1890	562	23	10	4	439	564	2143	2955
Surplus solar energy	1	2931	8194	10342	15143	13858	14810	12440	8010	3773	661	-1053
Electrolyzer feed kWh	0	2052	5736	7239	10600	9700	10367	8708	5607	2641	463	0
Fuel cell feed kWh	0	0	0	0	0	0	0	0	0	0	0	2056
PEM electrolyzer demand	-622160	-620108	-616424	-614921	-611560	-612460	-611793	-613452	-616553	-622160	-622160	-622160
Waste heat PEM	186648	186648	186648	186648	186648	186648	186648	186648	186648	186648	186648	186648
Surplus Waste heat	182757	183999	184693	184758	186086	186625	186638	186644	186209	186084	184505	183693
Compressor PEM-MP	-230	-230	-230	-230	-230	-230	-230	-230	-230	-230	-230	-230
Compressor MP-HP	-10166	-10166	-10166	-10166	-10166	-10166	-10166	-10166	-10166	-10166	-10166	-10166
Shortage electricity	-632555	-627573	-618626	-614975	-606812	-608998	-607379	-611408	-618940	-628783	-631895	-633609

Table10.2, Total energy production and demand of the Island

10.3 Energy demand appliances building

The energy demand of the applicances of the building is based on the surface and core numbers retrieved from Meijer PH, Verweij R, (2009). These numbers are still based on a analysis of exsisting buildings. The appliances used at that time may not be as efficient as the current ones. Therefore the exact number will be a bit lower.
In the table below the functions with the surfaces are listed with the corresponding core numbers kWh per year. This number is multipled by the surface and as an result of an average electricty demand per year for appliances of 43195 kWh, which is a average of 3600 kWh per month.

Energy demand appliances		
Research Centre/Living Lab		
Lab spaces	60 m2	60 kWh/m2
Meeting rooms (6p.)	32 m2	40 kWh/m2
Offices (6p.)	65 m2	50 kWh/m2
Wardrobe	4 m2	40 kWh/m2
Toilets	5 m2	15 kWh/m2
Storage	12 m2	10 kWh/m2
Total	**178 m2**	
Information centre/Expo		
Lobby	140 m2	40 kWh/m2
Checkroom	20 m2	40 kWh/m2
Café	75 m2	120 kWh/m2
Toilets	15 m2	15 kWh/m2
Toilets	15 m2	15 kWh/m2
Offices (4p.)	40 m2	50 kWh/m2
Main expo	166 m2	40 kWh/m2
Auditorium	50 m2	50 kWh/m2
Storage	10 m2	10 kWh/m2
Total	**531 m2**	
Bunker station		
Refill	10 m2	10 kWh/m2
Anchor spot	180 m2	10 kWh/m2
Material storage	30 m2	10 kWh/m2
Offices (3p.)	30 m2	50 kWh/m2
Total	**250 m2**	
Installation		
Air handling	100 m2	10 kWh/m2
Purification	30 m2	10 kWh/m2
Electrolyzer	90 m2	10 kWh/m2
Storage (mobile)	50 m2	10 kWh/m2
Compressor	32 m2	10 kWh/m2
Battery	10 m2	10 kWh/m2
Fuel cell	46 m2	10 kWh/m2
Storage	134m2	10 kWh/m2
Total	**492 m2**	

Table10.3, List of functions with the corresponding demand of the appliances

10.4 Energy demand heating and cooling

It is fair to assume that buildings demand more energy in intense weather conditions, for example in the middle of the winter. However, occasionally it is harder to calculate a more accurate energy consumption per month. Heating and cooling degree days can help to predict the fluctations per month. This will help to correspond the energy usage with weather trends in the region of Rotterdam. Heating degree days measure how cold temperatures are given for a period, as result a demand for energy to heat the building.
The first step is to have core numbers for heating and cooling per square meter 29 kWh/m2 is taken into account, this is retrieved from Aukema B., (2012). As result the total energy demand per year can be found, this is 19778 kWh per year. However, we want a more accurate energy demand per month. The base temperature taken is 18ºc, the average temperature is found from weerstatistieken.nl, this is based on data from KNMI retrieved from official stations. Therefore the heating and cooling degree days can be calculated, see table below.

Month	AvgTempC	HDD	CDD
January	2,0	418,6	0
February	5,3	285	0
March	8,7	210,3	0,8
April	8,7	203,3	0
May	14,9	60,5	41,3
June	18,3	2,5	86,1
July	18,1	1,1	82,6
August	17,6	0,4	64,2
September	14,2	47,2	7,8
October	13,8	60,7	6,7
November	7,8	230,5	0
December	5,2	317,9	0
Total		1838	289,5

Table10.4, Heating and cooling degree days per month

10.4 Installation scheme

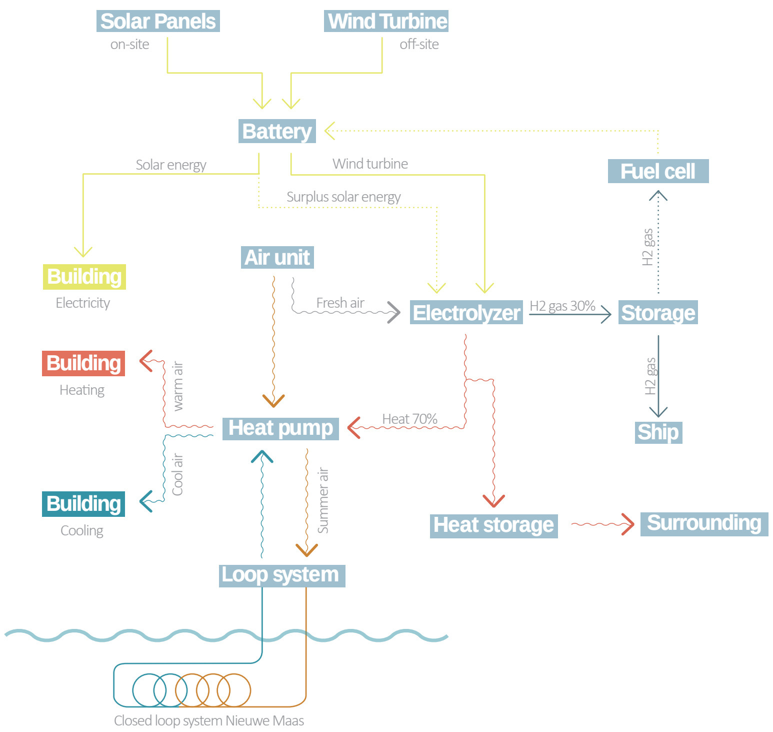


Fig.10.1, Installation scheme

The electricity that is required for the building is generated by the solar panels, that are placed on the facade and roof of the building. This energy is directly used by the building itself. When there is a surplus electricity, this will be used by the electrolyzer to produce hydrogen. However, the solar panels are not nearly enough, therefore to produce clean hydrogen wind turbines have to be placed off-site. A small part of the heat that is produced from the electrolyzer (30% hydrogen and 70% heat) is directly used to heat up the air that is going to be used for heating the building during wintertime. The rest of the heat is stored in the heat storage and can be used to heat the surrounding buildings. In the summer to cool the building a closed loop system in the Nieuwe

Maas is applied. In the summer the (warm) air from will be cooled through the closed looped system and the heat pump. By making use of cool air the functions can be rapidly cooled. This is necessary due to the large transparant surfaces of the facade, which can quickly lead into over heating the spaces. Below a section of the island is shown with the installation scheme.

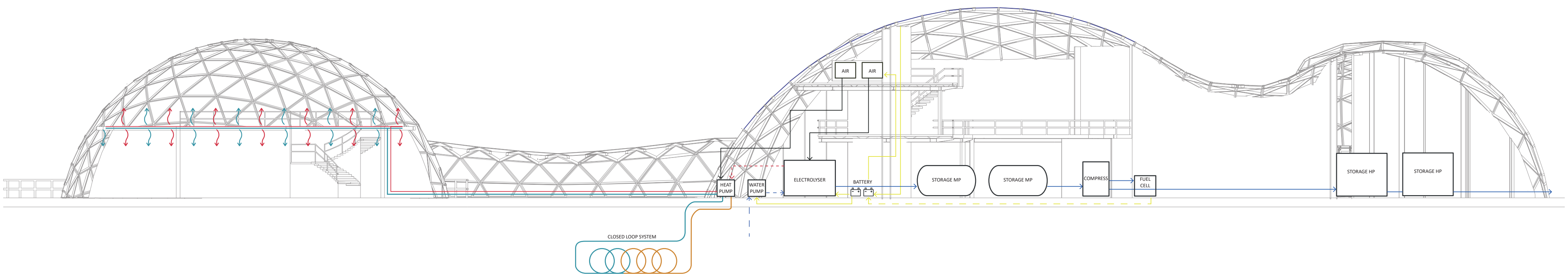
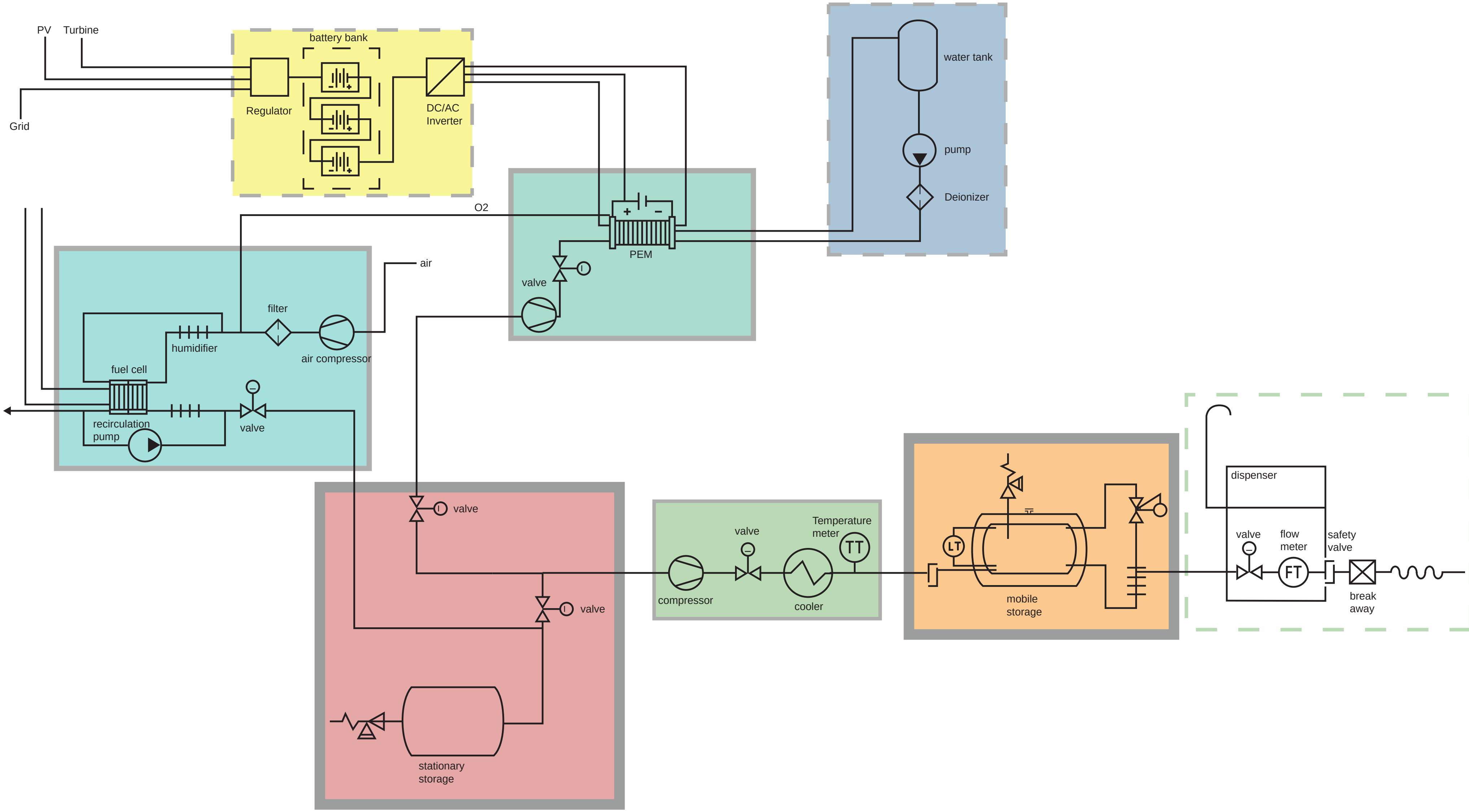


Fig.10.2, Installation scheme section island

10.5 Detailed energy diagram

Below are more detailed diagram is showed of the energy system. Each energy component is in away serperated from each other to minimze the chance of an accident effecting another component. Further reduce this risk ESD-valves are placed at the end and start of the component. These valves can have a dual function, on the one hand as a process valve and on the other hand as a safety shut-off valve. In addition, there are manually operated valves maintenance purposes. Before pumping hydrogen quickly under the required pressure on the ship, the hydrogen is cooled by a chiller. The temperature compensation is carried out with a temperature sensor in the head of the delivery hose that is linked to the cooler control. After the chiller a temperature sensor is placed, this gives an indication whether the gas temperature of the hydrogen in the the dispenser is not exceeded. A safe shutdown is ensured at exceeding the limit. The flowmeter is to determine the amount of hydrogen delivered and to adjust it and to stop the delivery by a too high outflow by activating an ESD-valve. A break away at the begin of the hose, this device automatically interrupts the hydrogen flow in a situation where the ship is not achored properly, while the delivery hose is still connected.


PV
Turbine
Grid
battery bank
Regulator
DC/AC
Inverter
water tank
pump
Deionizer
O2
PEM
valve
air
filter
humidifier
air compressor
fuel cell
recirculation
pump
valve
valve
valve
stationary
storage
compressor
valve
Temperature
meter
TT
cooler
LT
mobile
storage
dispenser
valve
flow
meter
FT
safety
valve
break
away

10.6 PEM electrolyzer

PEM Electrolyzers can perform at much higher current densities, manage to obtain values above 2 A cm^{-2}, resulting in a reduction of the operational costs and probably the overall costs of electrolysis, according to Carmo M., (2013).
He also mention that the low gas crossover rate of the polymer electrolyte membrane, yielding high purity hydrogen, allowing the electrolyzer operate under a wide range of power input. Because of the proton transport across the membrane responds quickly to the power input, not delayed by inertia as in liquid electrolytes. In comparison with alkaline electrolysis, PEM electrolysis covers essentially the complete nominal power density range (10-100%). One can assume that PEM electrolysis could achieve values over 100% of nominal rated power density, acquired from a fixed current density and its related cell voltage. The solid electrolyte allows for a efficient and compact system design together with strong and resistant structural properties, capable of withstanding high operational pressures (Medina P., 2010). With the electrolyzer operating at high pressure and therefore transfering hydrogen at high pressure for the end user, result into a reduction of energy consumption to further compress and store the hydrogen.

However, PEM electrolyzer also brings disadvantages. The corrosive acidic regime equipped by the PEM requires specific materials. These materials require not only resistance to low pH severe corrosion conditions, but also tolerate the high equipped over voltage, specifically at high current densities. Not only the catalyst should be corrosion resistant, but also the current collectors and seperator plates. Some particular materials can withstand this extreme environment. This will require the use of rare, expensive materials and components such as noble catalyst, composed out of platinum group metals (e.g. Platnium, Iridium, Ruthenium), titanium based current collectors and separator plates. Iridium got a major drawback, since it is one of he sacrest element on earth. Demand of this metal has increased lately, due to fabrication of LEDs applications(Carmo M., 2013).

Summary advantages and disadvantages PEM electrolysis

PROS
+ High current densities
+ High voltage efficiency
+ Good partial load range
+ Rapid system response
+ Compact system design
+ High gas purity
+ Dynamic operation

CONS
- High cost components
- Acidic corrosive environment
- Possibly low durability
- Commercialization
- Stacks below MW range

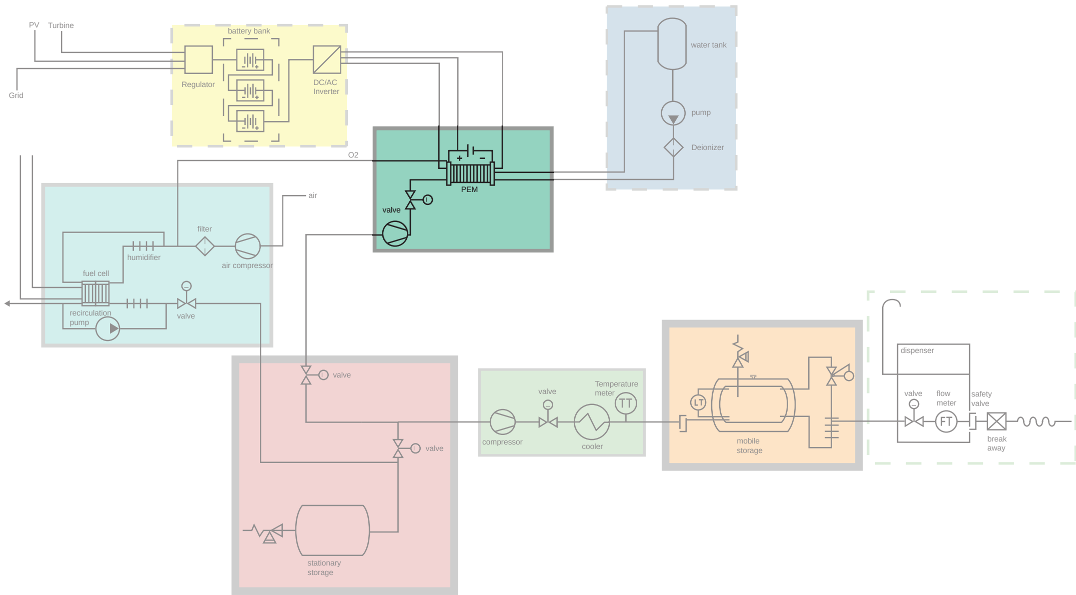
From all the different PEM electrolyzer, the Siemens SILYZER 200 has the preference. This is the most powerfull electrolysis system on the market and its highly dynamic operation allows it to be operated in the overload mode. This powerful electrolyser is required for the Island due the high hydrogen demand. The SILYZER has a modular design which makes it adaptable to the specific needs of the Island. This provides maximum flexibility with perspective on the future, when the demand of the hydrogen might increase. Especially the demand of the hydrogen powered inland ships, at this moment these are still in development. When they become more common, it is convenient if the electrolysers can easily adapt to the increase of demand. The basic system consist a minimum of 1.25 MW skid, combined with multiple systems it is easily expandable up to 20 MW or more. Operation connectable to volatile power generation and main grid connection, together with a rigid and low-maintenance design, free of harzardous substances, allows a stable hydrogen production. The obtained hydrogen is extremely pure, with nitrogen, sulfur, or carbon residues.

SILYZER 200 basic system
Technical data

Electrolysis type/principle:	PEM (Proton Exchange Membrane)
Rated stack capacity:	1.25 MW
Skid dimensions:	6.30 m x 3.10 m x 3.00 m
Startup time:	< 10 sec
Output pressure:	Up to 35 bar
Hydrogen purity:	99.5% - 99.9%
Hydrogen quality 5.0:	Optional DeOxo dryer
Hydrogen production under nominal load:	225 Nm^3/h
Life cycle design:	> 80000 hours
Weight:	1700 kg
CE conformity:	Yes
Fresh water demand:	1.5 l/Nm^3H_2

Figure 10.1. Siemes SILYZER 200, Retrieved February 5, 2018, from https://www.industry.siemens.com/topics/global/en/pem-electrolyzer/silyzer/pages/silyzer.aspx

PEM energy requirement



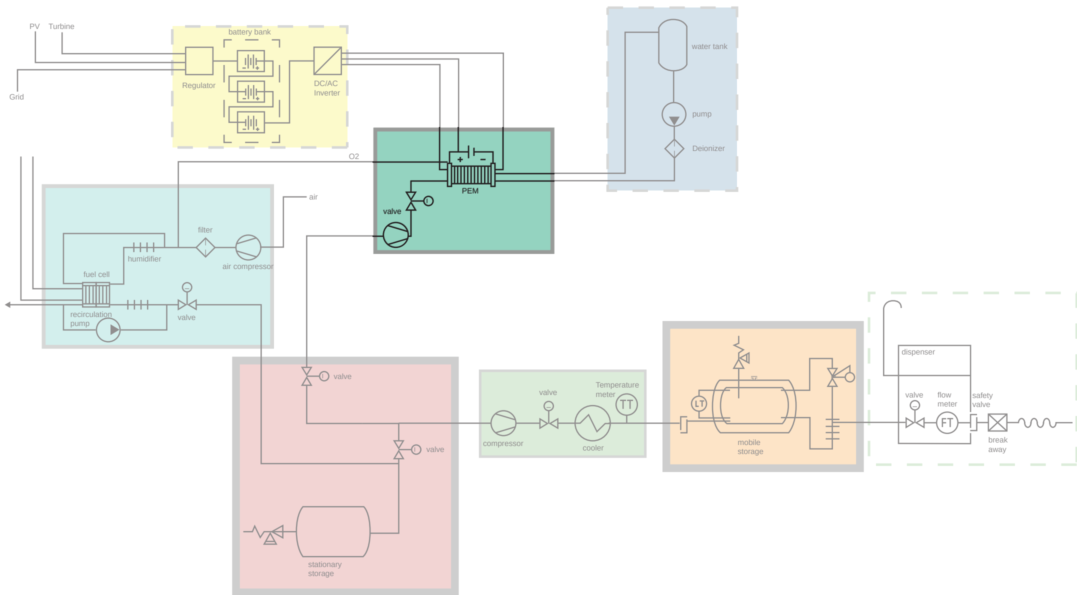
Required hydrogen		420	kg
Period		23	h
Required generation rate per hour		18,26	kg/h
Hydrogen production under nominal load		225	Nm^3/h
		20,25	kg/h
Rated stack capacity		1,25	MW
		1250	kWh
Operating at 90,17%		90,17	%
h2	18,26kg/h	1127	kWh
h2	1kg/h	61,72	kWh
	420kg	25924	kWh

10.7 Compressor (PEM-MP)

The electrolyser is not able to produce hydrogen directly to 50 bar, that is why a small compressor is connected directly to the electrolyzer. This is a small compressor, because it only need to compress the hydrogen from 20 bar to 50 bar into the middle pressure hydrogen storage.
The energy required for compression is calculated with the following formula:

$$W = [n/(n-1)]\ p0 * v0\ [(p1/p0)^{(n-1)/n} - 1]$$

Required electricity compressor (PEM-MP)



Ratio of specific heats (n)	1,41	
Initial pressure (p0)	20	bar
	2000000	Pa
Final pressure (p1)	50	bar
	5000000	Pa
Initial specific volume (v0)	11,11	m3/kg
Specific compression work (W)	2491890,654	J/kg
Density hydrogen	0,09	kg/m3
Required Joules per kg hydrogen	224270,1589	Joules
Required kWh per kg hydrogen	0,062297266	kWh
Total kWh for MP-HP compression	9,61 KWh	

10.8 Stationary storage (MP)

The intermediate storage is used to shorten the time period of bunkering. Also this storage can consist of several pressure vessels that are connected via a piping system. If there is not an intermediate storage is used, the high pressure storage will be directly filled via the compressor. Generally, the capacity of the compressor that is connected to an intermediate storage will be smaller than in the situation when the intermediate storage is not used.

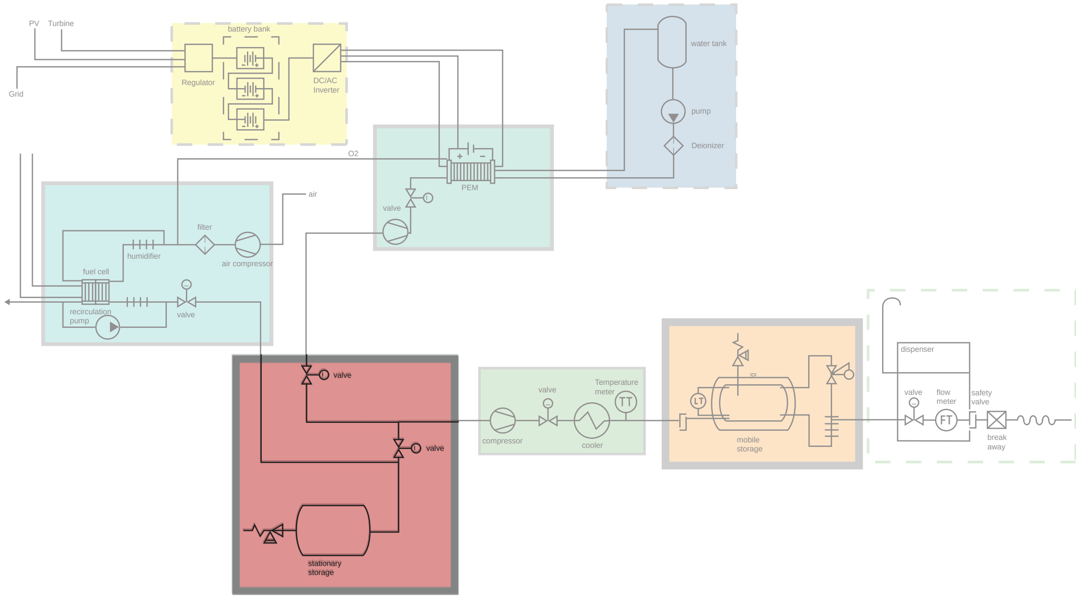
Type vessel	max. Pressure	Technology maturity	Weight performance	Cost performance
Type 1	50MPa	++	-	++
Type 2	**not limited**	+	0	+
Type 3	70MPa	-	+	-
Type 4	100MPa	-	++	-

Table10.4, Vessel types comparison

For the Island the hydrogen generated from the electrolyser will be compressed to a intermediate middle pressure storage of 50 bar. The type of vessel that is chosen for this is a type 1 aluminium storage. For the most logical reason is that a stronger vessel is not necessary, therefore there is no reason to apply a vessel that is a lot more expensive. The storage is located on a floating ponton, to miminze to weight, there is chosen for a aluminum type of storage. To calculate the required volume the ideal gas formula is applied:

$$V = \frac{n * Z * R * T}{P}$$

Required stationary storage (MP)



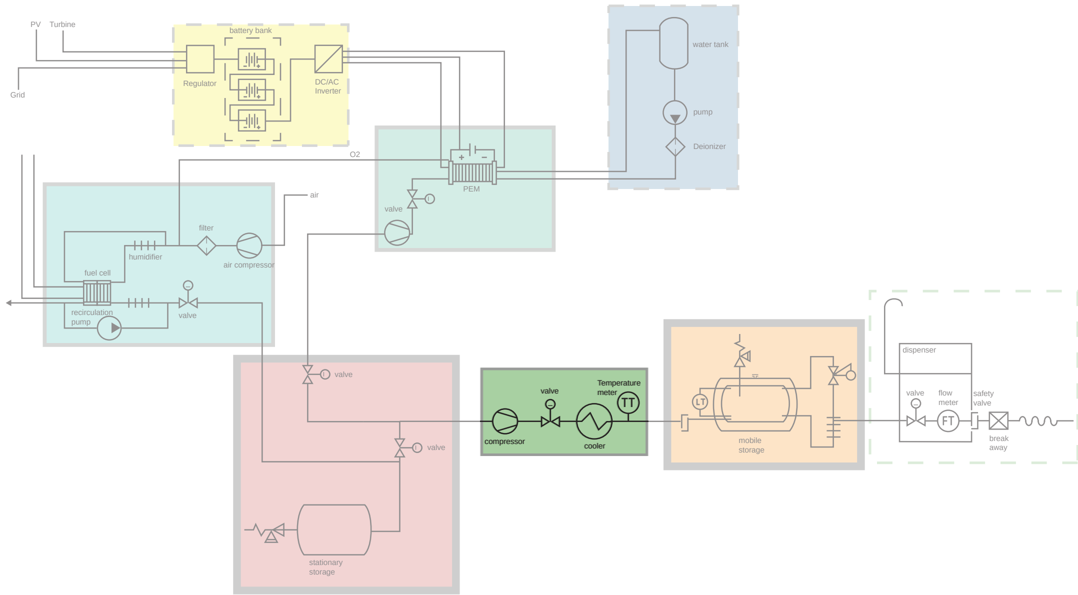
Required hydrogen	420	kg
Molecular mass per kg	496,06	mol
Total moles	208345,2	mol
Max temperature	38,2	celcius
Max temperature safery factor (20%)	45,84	celcius
Compressibility factor (Z)	1,427	
Gas constant (R)	8,134	J/mol*k
Pressure (P)	50	bar
Total Volume	154	m^3
	154264	L
Total Volume incl. safety (15%)	177	m^3
	177403	L

10.9 Compressor (MP-HP)

The proper pressure that is required for the ship is 350 bar. Therefore the hydrogen have to be further compressed. The compressor is much larger than the PEM to MP, due to the high pressure difference. This will also consume more electricity than the smaller compressor, see the calculation to the right. The energy required for compression is calculated with the following formula:

$$W = [n/(n-1)]\, p0 * v0\, [(p1/p0)^{(n-1)/n} - 1]$$

Required electricity compressor (MP-HP)

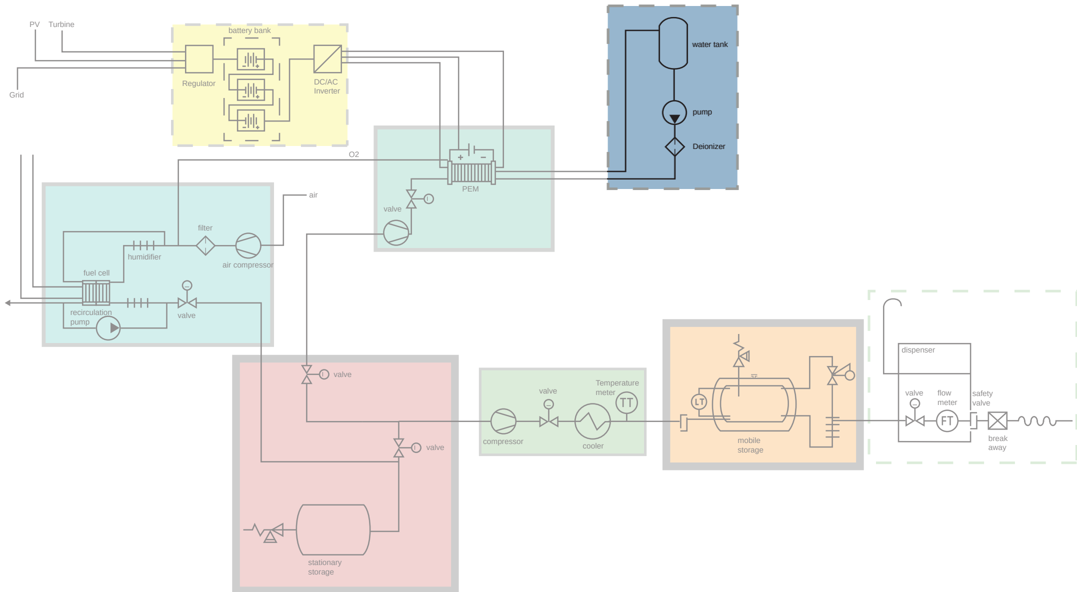


Ratio of specific heats (n)	1,41	
Initial pressure (p0)	50	bar
	5000000Pa	
Final pressure (p1)	350	bar
	35000000	Pa
Initial specific volume (v0)	11,11	m^3/kg
Specific compression work (W)	300877977,8	J/kg
Density hydrogen	0,09	kg/m^3
Required Joules per kg hydrogen	27079018	Joule
Required kWh per kg hydrogen	0,27	kWh/m^3
Total kWh for MP-HP compression	41,65	KWh

10.10 Water supply

The required hydrogen for the ship is 420 kg for a return, to produce this hydrogen a equivalent amount of water is required. This water is collected from the Nieuwe Maas. Before this water is used by the electrolyzer is has the be filtered by a de-ionizer, to ensure pure hydrogen. The required water for the electrolyzer is shown in the calculation on the side of the page.

Water supply



Fresh water demand	1,5	L / Nm³ H2
Water required per kg	16,7	L / kg
Water required (420kg)	6999,3	L
Operating at	90,17%	
Total water required (420kg)	6311,27	L

Chapter 11
Conclusion

11.1 Overall conclusion

Prior to the design is it important to understand the basics of hydrogen. Not only the advantages and disadvantages, but also how the current processes are. What the different possibilities are of producing hydrogen and storage, finding out what the most suitable components are for The Island. Therefore it is important what the energy system requirements are, this showcasing Island is intended for one inland ship. It is important to gain reliable numbers for the demands of the requirements. This is due to the fact that the ship consumes most of the hydrogen. The amount of hydrogen the ship consumes defines which energy components and storage is needed for the Island. Ballard has calculated a number of scenarios, but comes up with a 420kg hydrogen requirement for the return trip Alphen aan de Rijn - Rotterdam, with an optimal distribution of 600kW for the fuel cell and 200kW battery. Sustainability is an important factor and together with the requirements, the electrolyser from Siemens is the most suitable. With the water collected from the Nieuwe Maas, the produced hydrogen is compressed to 50 bar and stored in the middle pressure storage. From here the hydrogen is compressed to 350 bar and stored in the high pressure storage and ready to be bunkered.

The energy system should be safe and functional integrated in the design, however there is no existing comparable case. Therefore different proposals are made and evaluated with different experts. Together with further research the design and input from The Port of Rotterdam + safety guidelines, with the focus on sustainability, the design requirements are composed. These requirement are specified for this particular case, however they can be seen as universal guidelines for designing a building for hydrogen production and storage. The design requirements are:

- Location/context; outside of the safety contour, safety distances and central
- Logistics; stopover, separation, emergency services and collision protection
- Social impact; education, marketing and exposure
- Functionality; logical sequence, minimize pipe length and compartments
- Safety (prevent hydrogen accumulation); natural ventilation, weather protection, orientation and sensors
- Maintenance; replacement and inspection
- Acoustics; isolation
- Structure; fire-resistant and attractive
- Energy production; renewable energy production and integration

These design requirements are implemented the final design proposal “The Energy Island”.
The Energy Island is located in RDM with sufficient distance of the surrounding buildings outside the safety contours. The Island is connected to the existing dock where it is easy accessible for the public and emergency services. Social impact is an important factor, therefore the public functions, exposition, auditorium and café are introduced, but also “exposure” to the hydrogen system. To prevent the hydrogen to accumulate, the storage and research lab are open and by creating a venturi effect these spaces are ensured of a well guided ventilation. In case of a leak the sensors will pick this up and the whole system will shut down. The hydrogen system is located on the North, where this is less possibility of overheating. The whole system in placed in a logical sequence to minimize the pipe length. All the components is placed in compartments within in a risk-zone, in case of an incident it will minimize the chance of affecting the other components. There is sufficient space for replacement of the systems

and easy accessible check-ups can be done. The compressor is placed not directly to the façade, but in a closed space to isolate the noise. The structure represents the characteristics the of hydrogen, which is a sort of marketing for the hydrogen system. There have to be different intervention made to make the structure fire-resistant. The energy generation is only provided by solar panels, which are integrated in the building.

11.2 Recommendation

The process and design requirements are derived from the particular case "The energy island". In order to ensure that the list of requirements is complete other cases should be made. By working on other cases it can lead to new insights, due to their own particular restrictions. Next to improving the list of design requirements it can also develop better design solutions for a building involving hydrogen. An improvement that can be made for this particular design is that the hydrogen system should be more supportive for the building itself and the surroundings and research should be done of optimisation of the energy configuration.

Hydrogen is developing quickly, not only the components but also the practice. When the hydrogen become more common, the requirements will also be influenced. The government change their role involving hydrogen which can lead to more compliant guidelines.

1. Another case should be made to find out if there are missing requirements
2. Hydrogen system can support the surrounding functions
3. Hydrogen development influence the requirements

11.3. Reflection

How is your graduation topic positioned in the studio?

The track Building Technology exist out of one graduation studio, this is Sustainable Design. This studio is divided into three themes:
- Structural design
- Climate Design
- Façade Design
This project falls mainly in the theme climate and structural design.

How did the research approach work out (and why or why not)? And did it lead to the results you aimed for? (SWOT of the method)

The process of the research is started with the basics of hydrogen through literature study, with the results of the literature study, the first design proposals are made. It is important to start with a design proposal, because it is crucial to show how the hydrogen is integrated in the building. The proposal is evaluated with an expert in the hydrogen field. With the results evaluation of the opportunities and strength are further elaborated in the next proposal. At the same time further research of different aspects of hydrogen is taken place to support the design choices. This is a repetitive process, which eventually lead to an list of design requirements for this particular case involving hydrogen, however this still can be used as a guideline for other new building that want to in cooperate hydrogen. The threat of this design method is that it is time consuming, meaning that whole building design proposals have to be made and you are dependent on the expert in the field. The weakness is that final design proposal is not completely validated. The strengths are that obtaining these design requirements there is a lot of different perspective involved. Opportunities, people that want to design a building with hydrogen involved can start with these research results and can even lead to improved design proposal.

To what extent are the results applicable in practice?

The project energy island is a collaboration between TU Delft and The Port of Rotterdam. One segment of the energy transition is the use of hydrogen in the port. Port of Rotterdam is active contributing with different companies to the energy transition. The Island itself is substantial project, depending on the results it can be used as actual bunker station for an inland ship. This Island, next to the RDM is a first small showcase to demonstrate that inland ships can be powered by hydrogen. The components that are current applied are not yet entirely developed, as result a low efficiency. Eventually leading to a negative business case. Inland ships that are powered by diesel are a lot cheaper than hydrogen. According to Sendo Shipping to achieve a breakeven a price of €2 per kg of hydrogen should be realized, with current the development of facilities an investment of €2 mln will be required and the price of hydrogen will be around €7 per kg. If a scaling up will take place in the future it can reduce the price down to €2. However, these mentioned prices does not include any subsidy. Together with the development of the components and the pressure of government, hydrogen powered ships and therefore bunker stations will be inevitable.

To what extent has the projected innovation been achieved?

The whole innovative concept that architecture, energy/hydrogen production and bunkering has been achieved. The objective was to show how these completely different functions can be integrated safely and supporting each other

Does the project contribute to sustainable development?

This project is all about sustainable development, not only for the built environment but in combination with one of the most polluting transport. Maritime transport has an extremely high contribution to global air pollution. The shipping emits three air-polluting substances that have a considerable share of the total emissions on the Dutch territory. The objectives are to deliver an energy efficient building and trying convince more maritime transport to power their ships with hydrogen.

One of the setback, already mentioned above, is that the price of hydrogen are too high for shipping companies, which will make the shipping not profitable at this moment. Another setback is that at this moment there are a few companies that have the ability to transform their currents diesel powered ships into hydrogen powered ships. On the other hand these companies will not invest and provide a ship if there is no possibility to bunker hydrogen and act expectantly party a third party arrange a bunker possibility. This energy island will be a working project and hopefully convince and show other shipping companies that is a more obvious to sail with hydrogen. However, this project is a small scale project for capable generate enough hydrogen for one ship. In the future the scaling up and development of the components will reduce the price of hydrogen. This eventually will lead to an increase of ships powered by hydrogen.

What is the impact of your project on sustainability (people, planet, profit/prosperity)?

The current Inland ships are sailing mostly on diesel and by stimulating Inland ships to sail on hydrogen will reduce the overall polluting of the inland ships. Theoretically seen, if all the ships are powered by green hydrogen, there will be no pollution during transport. Another advantage of stimulating hydrogen usage is that it will also stimulate the development of hydrogen system. For example, if there is a higher demand of electrolysers this will lead to a higher and faster development of the product. Which will result in a higher efficiency and durability of the electrolyser, this will eventually reduce the end price of hydrogen. Eventually it will be comparable to traditional fuels or even cheaper.

What is the relation between the project and the wider social context?

The decision was deliberately made not locate the Island in an isolated place, where no one can see it. The goal is to inspire the public and to be aware how the sustainability works and demonstrate that hydrogen is fairly safe as long as it is handled with care. However, the majority of the people now, are still “scared” of hydrogen and not socially accepted. This is plays a big part of holding back the development of hydrogen and not being normalized in the society. On the other side there is a lot more progress. For example, the use of hydrogen cars are not used by everyone, but it is increasing. This is noticeable due increase use of hydrogen by public transport companies, but also to the available hydrogen cars for public. Gas station owners also going along with this development, more owners are adding hydrogen installations in their stations. The auto industry is always ahead of development, but for them it is becoming more standardized and when it is getting more common it will be easier for initiatives to receive a permit. Hydrogen as an energy carrier have a lot more potential than this Island and transport only. When is applied in a much larger scale, it is way more efficient.

How does the project affects architecture / the built environment?

The project affect the direct location (RDM) in a contrasting way. The surrounding buildings of the RDM are traditional buildings. However, this Research and development are allows innovative showcases. This project with the integration of the energy system and bunkering, together with the architecture assisting the system to ensure safety and efficiency, will be an inspiration for the built environment. The project also include a list of design requirements that is applied for this particular case, some of these requirement are context related. However, this list of requirements has a focus on safety and functionality of the hydrogen system. Therefore, it can be used as a general guideline for new buildings that include hydrogen.

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