Repurposing the Port: on the reuse of Aboveground Steel Oil-storage Tanks

Coen de Vries
Faculty of Architecture & the Built Environment, Delft University of Technology
Julianalaan 134, 2628BL Delft
b.c.devries@student.tudelft.nl

Abstract

The goal of this paper is to investigate the reuse potential of so-called Aboveground Steel Oil-Storage Tanks (AST's), as they might get superfluous in the continuation of the energy transition. To find out this reuse potential, the construction of these AST's is analysed and explained, after which a categorization is made of these AST's. Combined with an analysis of the chosen project-site – the Petroleumhaven-terrains in Amsterdam – this provides an overview of the construction, size and types of the potentially reusable objects. In the next part of the research, some challenges are of reusing AST's are outlined, being: providing daylight entry, the stability of the tanks, upgrading the building skin and the load bearing capacity of the AST's. For these challenges some directions of solution and points of attention for the design project are presented. To conclude, the paper states that AST's are reusable as objects, when taking into account the aforementioned challenges, and gives an overview of the starting points that are taken into the design project.

Keywords *Aboveground Steel Storage Tanks (AST's), reuse, object reuse, component reuse*

1. Introduction

Since the Industrial Revolution, fossil fuels have played, and continue to play, a dominant role in global energy systems, and thereby in the social, economic and technological developments worldwide. Unfortunately, these energy sources have their negative side-effects: local air pollution and global CO_2-emission. The latter has never been this high, resulting in an extra – more negative – important role for fossil fuels: in global warming. Not to mention that these fossil sources of energy are depletable sources; once we'll be running out of them.

If one takes a closer look, it becomes clear that one of these 'non-renewables' takes, with a percentage of 39%, a remarkable lead in the numbers: the usage of crude oil (Ritchie & Roser, 2020). Crude oil and – more often – products with oil as a resource, and the other big non-renewable source, coal, together form a large part of the transhipment, storage and trade in the Port of Amsterdam.

Following the plans and goals of the Dutch government to reach the globally agreed climate goals, in the so-called Klimaatplan (2019), the CO_2-emissions need to be lowered with 49% in 2030, and even to 90% in 2050. A large part of the solution to reach these goals is the development of renewable sources of energy, to prevent fossil fuels from being used. The city council of Amsterdam is even more ambitious: in their vision Nieuw Amsterdams Klimaat (2020) is stated that the city is striving to become independent of fossil fuels in 2050, and to phase out its' 'fossil activities' in the port and industry. By the year of 2030 this total part of industry has to be changed, for the reason that these fuels and connected industries are not sustainable and future-proof. That leaves the port-city with a large infrastructure, large constructions and architecture, in fact a lot of material and heritage.

In the same pace as the City of Amsterdam is phasing out its' fossil industries and activities, the demand for housing, offices, workplaces, utilitarian buildings and other facilities is growing, as are other cities worldwide. Amsterdam chooses to respond to this growing demand by expanding the city in the direction of the port. The combination of these conditions, a reduce in fossil activities and a largely growing demand for urban expansion, triggers a question of re-use: can the former 'fossil' industrial port areas be re-used to house this expansion?

1.1. THE SITE: PETROLEUMHAVEN AMSTERDAM

To answer this question an area is researched in Amsterdam, at this moment the words largest gasoline-port, and in the meantime trying to develop new (energy) strategies (van der Kroft, de Beaumont, & Brenninkmeijer, 2019). This international hub-function all started when the trade of gasoline and other oil products moved – because of the hazard level of the goods – outside of the city. The first port outside of the city, accommodating the oil-trade, was the Petroleumhaven (Bakker, 2011).

Due to both the fact that it was the first step to the immense growth of Amsterdam in the field of fossil fuels and the fact that this harbour is situated strategically for a possible extension of the urban region, this port-area is an interesting case study to investigate if, and how, it's possible to adapt and re-use certain plots.

1.2. INDUSTRIAL HERITAGE

In the second half of the twentieth century a specific type of industrial building lost its' use: the gasholder. With the disappearance of the use of town gas, due to the introduction of natural gas, these constructions, ranging from relatively small to enormously large, became vacant. A lot of these impressive brick or steel buildings were demolished, just because it was the end of their lifetime of their original use. Nowadays, a significant cultural and historical interest in these gasometers is growing. Being called 'industrial archaeology', the constructions are structurally recovered and transformed for new uses. (Fiorino, Landolfo, & Mazzolani, 2015)

Braae (2015) sees a future for all current industrial buildings to become, just like the gasometers, industrial heritage, and calls for a sustainable view on these areas, buildings and constructions. This research tries to answer this call, extending the life of the prospective post-industrial landscape of oil-related port areas: sustaining the industrial heritage of the future.

1.3. RESEARCH QUESTIONS

To be able to research if these former oil-related constructions can be reused, a study is done to categorize the most common of these constructions: the *aboveground steel storage tank (AST)*. From that point, an investigation is done on how these different categories can possibly be reused and what has to be done to make them fit for this purpose. The research tries to answer the following main research question:

How can aboveground steel storage tanks be categorized and reused to house new, urban functions?

In the process of answering this question, the following sub questions will be addressed:

- *How are AST's constructed and can different types of AST's be defined?*
- *What are the possibilities to reuse AST's, either as an object or as components/materials?*
- *What are the amounts per type of AST at the Petroleumhaven-terrains?*
- *What could be the relevance – and possible effect – of this research at a North-European scale ()?*
- *What are the possible challenges and directions of solution, when reusing AST's?*

1.4. RESEARCH METHODOLOGY

The research starts with a study to the construction and categorization of AST's, based on literature study and a number of interviews. With this information, a Material Flow Analysis (MFA) is used to analyze how much AST's of each type are present at the Petroleumhaven-terrain, as well as the amounts of material they consist of.

Thereafter, based on literature study, the reuse potential is examined. Along with that the challenges and possible solutions that come with this strategy of reuse are outlined.

2. Construction of oil-storage facilities

Although all these constructions seem similar, when one takes a closer look at oil-storage facilities, the so-called *aboveground steel storage tanks (AST's)* differences become noticeable. In an interview with Bastiaan Schepers (personal communication, April 2, 2020), technical manager at VTTI – currently the biggest company in the Petroleumhaven – he elaborated on these differences and similarities.

In the so-called atmospheric, low-pressure storage tanks, as are located at the Petroleumhaven, a classification is made based on the product that is (going to be) stored in the storage tank. All the oil-related products are flammable, but the minimum temperature at which a flammable mixture is formed just above the liquid, the so-called *flash point*, differs per product. In table 1 the classification that is used to categorize the different products based on their *flash point* is displayed. (*Richtlijn voor bovengrondse opslag van brandbare vloeistoffen in verticale cilindrische tanks*, 2008)

Table 1 Flash points of different oil-related products
(*Richtlijn voor bovengrondse opslag van brandbare vloeistoffen in verticale cilindrische tanks*, 2008, p. 12)

Class	Flash point (FP) boundaries	Examples
K0	FP < 0˚C	Products of K0-class are never stored in atmospheric conditions
K1	FP < 21˚C	Gasoline, benzene, toluene, petroleum ether
K2	21˚C ≤ FP ≤ 55˚C	kerosene, turpentine, solvent naphtha
K3	55˚C < FP < 100˚C	diesel oil, gasoil, light fuel oil
K4	FP > 100˚C	heavy fuel oil, lubricating oil

2.1. CATEGORIZING OIL-STORAGE

The construction of the storage tank differs per class of the product that it contains. In the Petroleumhaven no 'K0' (class 0)-storage is done, the three classes that are stored and handled at this plot are K1, K2 and K3-tanks. The main difference between the storage facilities for these categories regards the construction of the roof.

Due to the high flammability of K1-products, a minimum amount of air, and by that oxygen, is preferred in the tank. That's why amongst other reasons a so-called *floating roof* is used, a roof that literally floats on the liquid product. Both K1- and K2-products require such a roof for storage, K3-products are stored in tanks with a *fixed roof* construction (Schepers, personal communication, April 2, 2020).

2.2. TANK PITS

AST's are situated in groups, with a prescribed maximum number of tanks and a prescribed spacing in between the tanks. Due to environmental regulations, these groups have different safety requirements, to prevent spilling of the oil and other stored products to (ground)water and soil-surfaces. The most common measure that is taken is building a dike, berm or retaining wall around these tanks-groups, from which the specific terminology of a *tank pit* arose. (Digrado & Thorp, 1995)

2.3. FOUNDATION

The type of foundation used in the design of AST's, differs per tank and depends largely on the tank size, site conditions and environmental requirements. Five common foundation types are defined in the *Guideline for Tank Foundation Designs* (2005):

1. Concrete Ringwall
2. Crushed Stone Ringwall
3. Concrete Slab
4. Compacted Granular Fill
5. Pile foundations

The last option, piled foundations are only used on soils where no other foundation type is feasible. The first and second option, the concrete and crushed stone ringwall (also earthtype foundation) should be used for large storage tanks (ø ≥ ca. 15m). Small tanks (ø ≤ ca. 15m) can be founded on concrete slab foundation or compacted granular fill foundation. In both the cases, the concrete foundation is preferred and – since flooding and seismic effects are quite often possible phenomena – anchorage of the AST's should be taken into account. (Digrado & Thorp, 1995; Pierluigi, 2014; *PIP STE03020 Guideline for Tank Foundations Designs*, 2005; Zdravkov, n.d.-a)

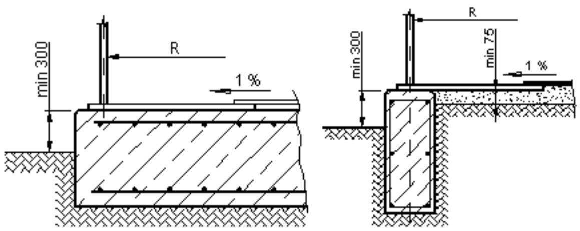

Figure 1 Typical concrete slab (left) and concrete ring (right) foundation (no scale) (Zdravkov, n.d.-a)

Considering these regulations and guidelines and projecting them on the project location, the Petroleumhaven, it is assumed for this research that, due to the in general unstable soil in the Netherlands, concrete ringwalls (large tanks) and concrete slabs (small tanks) are used as a foundation.

2.4. BOTTOM

The bottom of an AST is made of the same material as the shell and the roof: most often carbon steel is used, in exceptional cases stainless steel. The minimum thickness of these steel sheets is, as prescribed by the NEN-14015 norm (2004), 5-6 millimeters. The different sheets are welded together on-site, following typical layouts and welding details, as showing in *figure 2.*

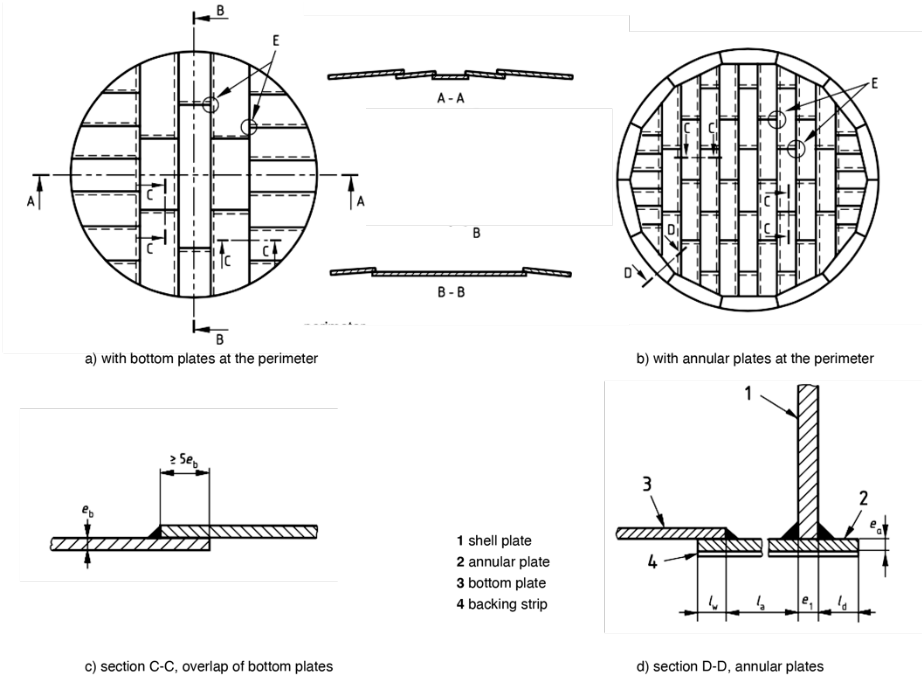

Figure 2 Typical bottom lay-outs and connection details (no scale)
(*NEN-EN 14015 (en)*, 2004, pp. 41–42)

2.4. SHELL

The design of the shell, the walls, of an AST is depending on a few principles: the material of choice, the thickness of this material and of course the tank size (diameter and height). These, in turn, are determined by local regulations (as for example the NEN-14015 (2004) in the Netherlands), the product that the tank is going to contain and site-specific seismic and wind-pressure conditions. (Digrado & Thorp, 1995)

The shell of most AST's is made out of carbon steel, with specific corrosion characteristics and if necessary a specific coating, both depending on the product that is going to be stored. The shell is built up out of separate, pre-bended steel sheets, welded together on-site. Because the pressure of the stored product on the shell is lower at higher parts of the tank, the thickness of the shell material is greater at the bottom of the tank than at the top. The interview with Bastiaan Schepers (personal communication, April 2, 2020) learned that the thickness can range from 6 millimetres at the top of smaller tanks to 13 millimetres at the bottom of larger tanks. Drawings of Zdravkov (n.d.-b) of a typical storage tank with a diameter of 22,8 meters show a similar range with plates of 10mm at the bottom to 7mm at the top.

As further elaborated on in 'Challenges & solutions', the AST's know a shared risk, due to their light and thin structure: the risk of *buckling*, large deformations of the tanks due to internal or external pressure. To prevent this from happening, the constructions need to be checked to ensure they are stable enough. Tanks with a fixed roof often are by itself already so, but especially *open top tanks* need at least one *wind girder*, also called *stiffening ring,* at the top of the tank. Both the constructions may need, if the shape or ratios are such, an extra *wind girder* added halfway or on another height. (Digrado & Thorp, 1995; *NEN-EN 14015 (en)*, 2004)

2.5. FIXED ROOF CONSTRUCTION

Since the shell structure can be stabilized using *wind girders*, roofs aren't unmissable for this purpose. But, to keep rainwater, snow and other external elements from contaminating the product, prevent loss of product due to evaporation, reduce the emissions of air pollutants or to maintain a certain pressure for specific products, a roof can be used. (Digrado & Thorp, 1995)

In the aforementioned classification based on the *flash point* of different products that are stored in the AST's, the difference in roof type between K1/K2-products and K3 types was already introduced. K3-products are, due to their relatively low *flash point* and therefore relatively low danger when in touch with air, stored in the simplest form of the AST: the *fixed roof storage tank.*

This type consists of a column-supported or self-supporting roof structure, that – as mentioned before – also has a role in the stabilization of the shell structure. Fixed roof constructions are not standard building elements: these parts of AST's differ, depending on the designer, engineer and constructor of the tank. However, some data is available about this type of roofs. The used steel profiles for the cone- or dome-shaped constructions, for example, can range up to IPE360- or even IPE400-profiles ("Tankconstructies: dakconstructie," n.d.). In *figure 4* a scheme of both the shapes and configuration of fixed roof constructions is displayed. ("Atmospheric Storage Tanks," 2008; *NEN-EN 14015 (en)*, 2004; Lees, 1996)

The roof is cladded with on-site welded carbon steel sheets, comparable to those used for the shell, but (most of the times) thinner (with a minimum of 5 mm for carbon steel). This construction type knows two shapes: dome-shaped and cone-shaped fixed roofs. The slope of a cone-shaped roof is 1:5 for self-supporting – with or without a truss-construction – roofs, and 1:16 for column-supported roofs. ("Atmospheric Storage Tanks," 2008; *NEN-EN 14015 (en)*, 2004)

2.6. FLOATING ROOF CONSTRUCTION

To make *fixed roof* AST's suitable for the storage of both K1- and K2-class products, an *internal floating roof (IFR)* can be added. As the name suggests, this roof floats inside the tank on the stored liquid, to keep the product from evaporating and mixing with air: this way preventing the loss of the product as well as air pollution and a higher risk of flammability. ("Atmospheric Storage Tanks," 2008)

Tanks can also be suited with an *external floating roof (EFR)* construction, providing the same safety and environmental advantages, but without the *fixed roof* installed. As mentioned before, this type of AST, also called *open top* roof tanks, has to be fitted with *wind girder* to create a stable and stiff shell structure.

As shown in *figure 3* floating roofs can be categorized in six types, of which three are also suitable as *external floating roof*:

- Pan (internal + external)
- Compartmental (internal)
- Annular pontoon (internal + external)
- Double deck pontoon (internal + external)
- Deck-on-floats (internal)
- Sandwich panel (internal + external)

(Digrado & Thorp, 1995)

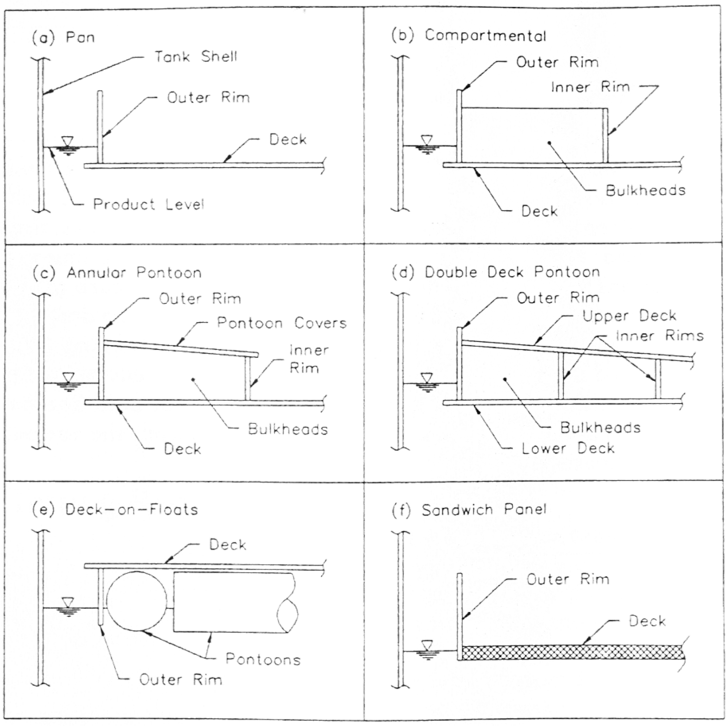

Figure 3 Sectional schemes of different types of *floating roof* constructions (no scale)
(Digrado & Thorp, 1995, p. 154)

To prevent storm water from overloading the external floating roof an aluminium geodesic dome is sometimes added as a top to AST's. This dome-shaped roof is, next to its' preventive role, an extra barrier for (environmentally) dangerous vapours to leave the tank. ("Atmospheric Storage Tanks," 2008; Sprung, 2018).

When looking at the Petroleumhaven, all the EFR- and IFR-tanks are fitted with composite sandwich-panel roof construction, in some cases expanded with a geodesic dome roof on top of the tank. All the fixed roof AST's are fitted with self-supporting roof structures.

2.7. CATEGORIZATION AND THE NUMBERS

From the foregoing information, a clear categorization can be extracted. As also displayed in *figure 4* this categorization is mainly based on the split into two types: the *fixed roof* and the *open top* type. Both types have specific characteristics and their possible additions or variations. A second split is made in the type of *fixed roof* tanks, in tanks with and tanks without an *internal floating roof (IFR).*

In *appendix A* a material flow analysis (MFA) is presented of the Petroleumhaven-terrain, showing both the tank types and sizes per terrain (and company), analysed per *tank pit*. From this analysis, a breakdown is displayed in the types and amounts of components and materials that are incorporated in the different AST's. The numbers, sources and formulas that are used for this MFA, are shown in the table in *appendix B.*

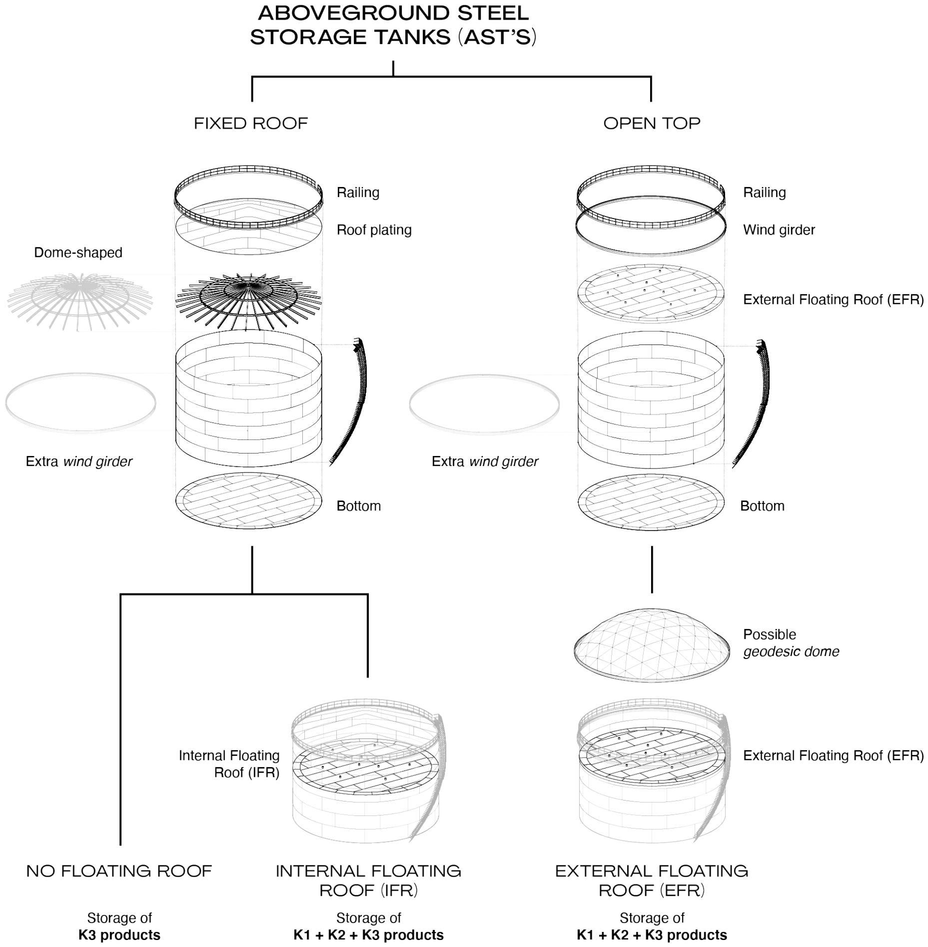

Figure 4 Categorization of Aboveground Steel Storage Tanks (AST), own image (data: ("Atmospheric Storage Tanks," 2008; Digrado & Thorp, 1995; Lees, 1996; Sprung, 2018)

2.8. RELEVANCE OF THE PROJECT

A quick inventory learns that, of the biggest European ports, quite an extensive part of the trade, storage and distribution in the port involves liquid bulk goods. In this field, the biggest North-European ports are, in order of quantity – Rotterdam, Antwerpen, Amsterdam, Le Havre and North Sea Port (*2019 Feiten & Cijfers*, 2019). When focusing, of these liquid bulk goods, on only the oil-related products, an estimation can be made of the scale of the Port of Amsterdam, and its' reuse potential, compared to a European scale. In *figure …* an overview is given of these amounts. In this scheme the specific weight of the oil-related products is assumed to be 0.75 (the average specific weight of crude oil and most oil-products) ("Fluids - Specific Gravities," n.d.).

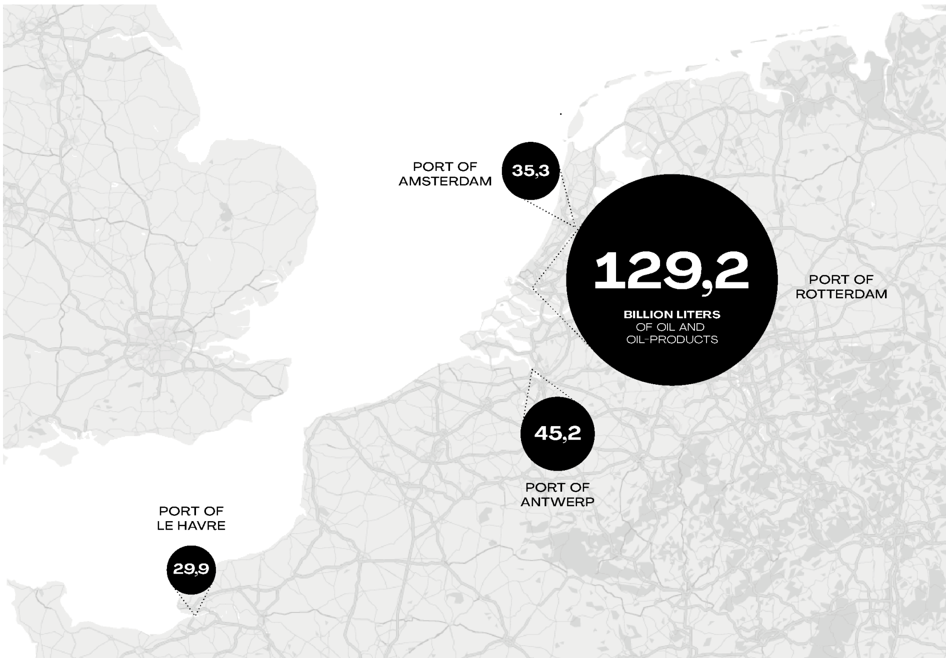

Figure 5 Amounts of yearly trade of oil and oil-products in 2019, in billions of litres
own image (data: (*2019 Feiten & Cijfers*, 2019; *Goederenoverslag in de haven van Rotterdam*, 2020; *Jaarverslag 2019*, 2020)

3. Reusing oil-storage facilities

As Addis (2006) states, the main reason for re-using building materials and components is to lower the enormous impact the building industry has on the environment. Of this impact, three main causes can be identified: the depletion of non-renewable resources, road transport and manufacturing process that are producing air pollution and the degradation of landscapes, due to material extraction in for example quarries, woods and landfill sites.

A lot of building materials and components have a difficulty to be reclaimed, causing their re-use potential and likeability to be low. Steel, in contrary, is relatively easy to separate and has therefore a fairly high rate of reclaiming. In 2018, 96% of the construction steel was reclaimed in 2018, of which 91% was being recycled – downgraded – and only 5% was being re-used at the same level (Gorgolewski, 2018). The latter, reuse at equal grade, is the one this research is pursuing to develop: to '*ensure […] that steel remains a permanent resource for society'* (*Steel in the circular economy: a life cycle perspective*, 2015, p. 3). By doing so, the amount of new steel needed is also reduced, providing a larger win in the environmental impact of building with steel.

When re-using, four types can be distinguished:

1. Reusing an existing structure on the site, and possibly extend it, change it or add to it.
2. Demounting materials and components of an existing building and reuse it at a new location.
3. Reusing individual components and materials, extracted from the demolition of one project, in a new building.
4. Use materials and components that were previously used for a different purpose.

This separation, as presented by Gorgolewski (2018) is used to investigate the challenges and possibilities for reuse in this specific project. As, due to the interesting and – suggested – historically valuable urban set-up of the site and its' constructions, the research will focus on the first method: in brief defined as *object reuse*.

The second method is not applicable to this project, because the materials are reused on-site. The third point, abbreviated to *component reuse,* is put into practice to reuse certain components that are demounted or come available in the process of *object reuse.* Of course, this project also uses materials and components with originally another purpose, as defined in the fourth point.

4. Challenges and solutions

Based on both a technical review of the current construction stock, and the outlined information on the construction of AST's, some challenges and possible solutions to these challenges are outlined.

4.1. GENERAL CHALLENGES

The reuse of steel, as this project is mainly based on, currently faces some challenges in the construction industry. First of all is a cost-related issue, as Gorgolewski (2018) points out that *'there is a perception in industry that reuse of steel is more expensive than new steel, and this was confirmed by analysis'* (4.3 Reuse of Structural Steel, par. 3). He continues stating that the difference is really small, creating the opportunity to overcome this quickly by larger-scale operations and improved infrastructure.

Another challenge the steel industry is facing is certification: in the reuse of steel it's difficult to ensure its' strength, durability and other properties defining the quality and usability of the reused steel (Gorgolewski, 2018)

4.2. DAYLIGHT

Taking an industrial object, as an AST is, as a starting point for a design strategy of repurposing, generates a core challenge: industrial buildings and constructions don't have any regulations on the topic of daylight entry ("Daglichttoetreding," n.d.). In amongst others residential buildings, offices and for example schools – in contrary – daylight is seen as the preferable way to *"to adequately illuminate the indoor surfaces, and to save energy for electrical lighting"* (*NEN-EN 17037: Daylight in buildings*, 2018, p. 6). One of the main tasks of the designer in planning the reuse of the AST's thus becomes the realization of daylight entering the building. Of course, this challenge only has to be overcome when a design strategy is chosen in which the newly developed units or functions are placed on the inside of the existing construction.The Dutch *Bouwbesluit* (2012), the national building regulations, also set some boundaries and rules on the topic of daylight entry, and the minimal required size of windows or other openings in the façade. In *table 2* these minimal areas are displayed, broken down per functional use of the building.

These amounts give a quick insight in the size of the necessary openings in the shell of reused AST's, but are only the minimal numbers. However, experience in using the *Bouwbesluit* shows that these minimal rules are quite low. In the later presented norm *NEN-17073* (2018) the amount of daylight is therefore not calculated on the basis of the window or opening size, but on the basis of the amount of 'lux' – the unit to measure the amount of light – that is available in certain parts of the floor area. A combination of both the *Bouwbesluit*-document and the *NEN-17073* will be used to solve the daylight-challenge in the design project.

Table 2 Minimal requirement for daylight area (windows / façade opening) in buildings (*Bouwbesluit 2012: Afdeling 3.11. Daglicht*, 2012)

	Minimal daylight area (windows / openings)	
Function of the building	**Percentage of floor area (%)**	**Area (m²)**
Residential function	10	0,5
Assembly function		
For childcare	5	0,5
Other assembly function	-	-
Detention function	3	0,15
Health care function	5	0,5
Industrial function	-	-
Office function	2,5	0,5
Temporary accommodation function	-	-
Educational function	5	0,5
Sports function	-	-
Retail function	-	-
Other functional use	-	-
Structure other than a building	-	-

4.3. STABILITY

Cone-, cylinder- and dome-shaped constructions, as almost all of the oil-storage facilities are, have a general issue of being very sensitive to imperfection in components, resulting in significant reductions of their bearing capacity and stability (Ifayefunmi & Błachut, 2018). This results in the danger of large deformations, the so-called *buckling* of the tanks, especially when these are empty. *Buckling* of storage tanks can be caused by external factors: wind pressure, fire or, causing the most displacement, seismic movements. But construction errors, such as corrosion of plates or issues happened during the welding process, can also increase the chance of *buckling*. (Sun, Azzuni, & Guzey, 2018). One of the construction-related imperfections, causing *buckling* sensitivity is defined as '*presence of material discontinuity or crack(s) on the shell structures'* (Ifayefunmi & Błachut, 2018, p. 1). Due to the aforementioned need to create windows or openings in the shell of the AST's, this last aspect, together with the point that the *buckling* sensitivity is higher when the tanks are empty, presents the design project with quite a challenge.

Two possible solutions are outlined in this paper. The first one, as put into practice at the *Gashouder*-project (HET Architectenbureau, 2008) is solving the issue of deformation by strengthening the sides of the cut-out part of the shell. To do so, a strip is welded – orthogonally – to these sides, as shown in *figure 6*. An interesting detail in this drawing is that the welded strengthening strip has the same properties, in material, thickness and finish, as the core material of the shell-structure. This provides the design project with the opportunity to eventually reuse the cut-out parts, the 'left-overs', as strengthening strip, cut and welded on-site.

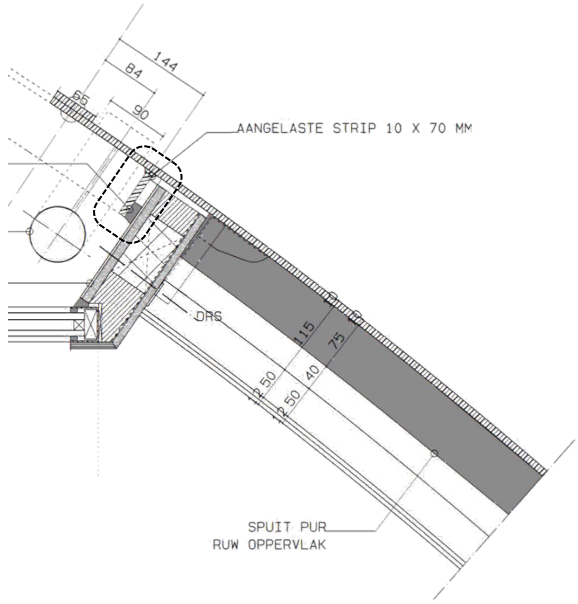

Figure 6 Detail drawing of an opening in the shell structure of the *Gashouder* (scale 1:10)
(HET Architectenbureau, 2008)

A second opportunity can be sought in the addition of a (extra or alternative) *stiffening ring* or *wind girder* to the AST, to ensure that the structure holds its' shape. Looking at the sectional drawings of these *wind girders*, as shown in *figure 7,* this solution could possibly as well be produced as a project of *component reuse,* using available materials and components. A second way could be to reuse a *wind girder,* reclaimed from another AST, as a component.

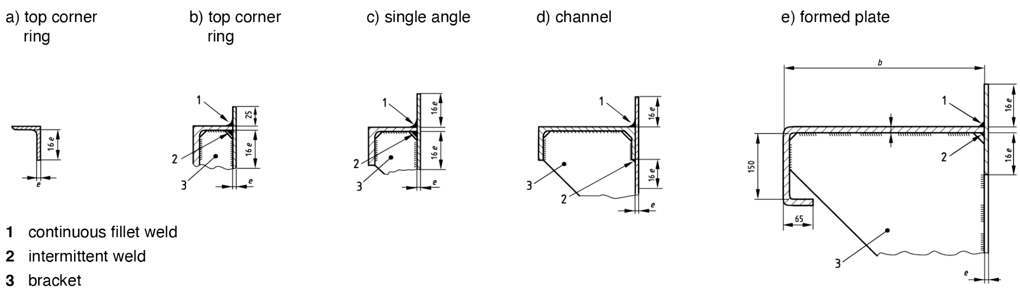

Figure 7 Typical sections of *wind girders*
(*NEN-EN 14015 (en)*, 2004)

4.4. BUILDING SKIN

Another challenge of reusing AST's, especially when the interior is transformed to liveable environments such as residential buildings, workplaces or other human functions, is the building skin. Assuming the characteristic exterior of the AST's is kept as the exterior façade, the interventions will be done on the inside. To create, somewhat energy-efficient, climatized indoor environments insulating the shell is inevitable. The used carbon steel has a λ-value (thermal conductivity) of 50 W/mK, resulting with an average thickness of 10 millimetres in an R-value of 0,0002 m²K/W, where an R_c-value (the total R-value of a wall) of 6,0 is prescribed by regulations.

In addition to the challenge of insulating the tank, the AST's are of course characterized by their watertight, vapour sealed constructions. When used as an external wall/façade, this property is quite useful, but needs another design approach than usual in climatized construction. Due to the flux of heat from inside to outside the structure of a wall, a difference in the air temperature, and thereby its' ability to carry moist, occur. This may result in condensation inside the wall build-up, which in turn can cause mould in different materials, cause damage by possible freezing or in any case decrease the insulation coefficient of the structure.

Where in regular building projects for this reason a watertight, but damp-open layer is added on the outside of the construction, a possibility for this project would be to ventilate the construction by perforating the shell and add a ventilated cavity. But, since this would decrease the insulation value – and therefore require a larger construction to insulate the building – and have an impact on the exterior quality of the shell this is not the preferable option. An interview with the transformation architect of de *Gashouder* in Naaldwijk, René Hoek (personal communication, April 24, 2020) showed that this solution is on top of that quite expensive. In the transformation of this project, they made use of a vapour sealed and watertight insulation method: PUR-isolation. This solution is more efficient: a thinner layer of this material is needed and it's less expensive. One issue: the PUR-isolation gets inseparable connected to all the surrounding construction elements, including the original shell of the building.

To broaden the range of vapour-sealed insulation methods, a comparative research is done. The results and the corresponding insulation value are showed in *table 3.*

Table 3 Comparison of vapour-sealed or moist-resistant to damp-open insulation methods ("Isolatiematerialen en hun eigenschappen," n.d.)

Layer	**d** (mm)	**λ** (W/mK)	**R** (Km²/W)	**Pros (+) /cons (-)**
Polyurethane (PUR)	140	0,023	6,1	- Greenhouse gas emission (so-called HFK's) - Inseparable connection, not circular/demountable
EPS-panels	200	0,033	6,1	+ moist-resistant, durable material
Polyester-wool	210	0,035	6,0	+ moist-resistant + material (can be) produced from plastic waste
Cork	230	0,038	6,1	+ moist-resistant + bio-based, ecological material
Glasswool	240	0,040	6,0	- not moist-resistant: danger of mould and decrease of insulation value
Flux / cotton	240	0,040	6,0	+ bio-baed, ecological material + can be grown on-site - not moist-resistant: danger of mould and decrease of insulation value

4.5. LOAD BEARING

Because the original use of the AST's, the storage of liquid products, only applies *uniformly distributed loads* on the construction, a third challenge is presented by the distribution of possible new loads of new (building) elements. As these are often build using columns or bearing walls, instead of *uniformly distributed loads,* so-called *concentrated loads* or *point loads* are applied.

As seen in the description of the foundation of AST's, these foundations are often only located under the shell. If one wants to put a construction inside the AST's, to build for example multiple floors inside or on top of the tanks, either a distribution of the load needs to be engineered or an extra foundation needs to be laid for the construction.

The latter sounds difficult, but in multiple cases of tank building and -maintenance companies is indicated that it is possible, and even quite usual, to lift tanks. Since their empty weight is not that high, and the AST's aren't inseparable anchored to their foundation – sometimes not even anchored at all – this process is relatively feasible (Holmatro, n.d.; Verwater, n.d.). This way, if only the distribution of loads isn't sufficient, additions or changes can be made to the foundation of the tanks.

5. Conclusion

Having outlined the core components and the construction of *aboveground steel storage tanks*, the categorization that can be made and the challenges that are, undoubtedly not yet all, presented for the design project, this paper provides the project with some valuable knowledge and tools. First of all, when repurposing an area and its' existing building and construction stock, knowledge of the current situation, both on an urban and an architectural scale, is unmissable. Since this knowledge was not found, gathered and with a clear overview, this paper will function as such: a reference for this knowledge during the continuation of the design project.

The first research question is answered by the aforementioned, complemented with the splitting of AST's in *open top* and *fixed roof* storage tanks. The difference is mainly demonstrated by the difference in products that are stored: products with a lower *flash point*, he so-called K3-products, are often stored in fixed roof tanks, while products with a higher flammability, K1- and K2-products are more often stored in *open top* tanks. In fact, the difference in the storage of products is in the addition of a *floating roof*, *external (EFR)* in the case of *open top, internal (IFR)* in the case of *fixed roof* storage facilities.

This paper focused, out of the four presented ways of reuse, on that of *object reuse*, while trying – in a secondary trajectory – to reuse amongst others reclaimed components and materials as *component reuse* during this process. For this type of reuse, some major challenges are found, that of *daylight entry, stability, building skin* and *load bearing*. In *table 4* the presented directions of solution and points of attention for the design project are outlined.

These aspects will play an important role as both technical and architectural starting points for the design process. Of course, next to this quite technical point of view, the reuse of such construction also incorporates important challenges and possibilities from an urban and architectural angle. The roundness of the tanks, for example, is a characteristic that can generate interesting, fluid urban spaces, while architecturally being an interesting starting point for a new type, non-orthogonal architecture that we're so used to. Subsequently, an important point of study for the next phase of the design project will be to find the right level of density for the area, from an urban and architectural as well as a technological perspective.

Table 4 Challenges and possible solutions in the *object reuse* of AST's

Challenge	Description	Direction of solution
Daylight	- No daylight entry in the current construction of AST's	- Logically, perforate the building skin to create windows and openings, providing the interior with enough daylight - Decide on program and the required/wished amount of daylight for this use(s) early in the process - This choice affects the measures that has to be taken in the field of *stability,* and thereby the technical intervention needed.
Stability	- AST's have a shared danger of *buckling*, large deformations due to internal or external (e.g. wind) pressure - This danger of instability is higher when the shell is discontinuous and when the tanks aren't filled with liquid products	- First solution is the addition of a welded strip around the openings in the shell, to recover the stability and the force transfer - Second solution could be the adding of a (extra or alternative) *wind girder* - For both the cases the possibility of *reuse of reclaimed components or materials* should be investigated and strived for.
Building skin	- The possibility of moist, condensing in the construction and/or insulation of the structure, causing mould or decrease of insulation value.	- Highly ventilated structure and insulation, to prevent moist from condensing and/or staying in the construction - Use of moist-resistant or vapour-sealed layers and/or insulation materials
Load bearing	- Since the AST's are normally only experiencing *uniformly distributed loads*, the foundation and materials used are not (always) able to resist *concentrated loads.*	- Addition of foundation (elements) - Distribution of loads, using load distributing components (e.g. base plates for columns) or other methods - Possibility of, relatively easy, lifting of AST', to add to or change foundation.

"Instead of searching out the best, calling it heritage and fighting to preserve it, we should look at everything around us and accept it all as cultural heritage. Proceeding from there […] we can determine the most appropriate ways of using it to create social values and added value for the future" (Braae, 2015, p. 76)

This statement provides an interesting conclusion to this paper and an inspiring introduction to the theme in the continuation of the design project. Creating the cultural heritage of the future and an alternative way of extending the city, while reducing the use of raw materials, could be one of the components of our fossil-free future.

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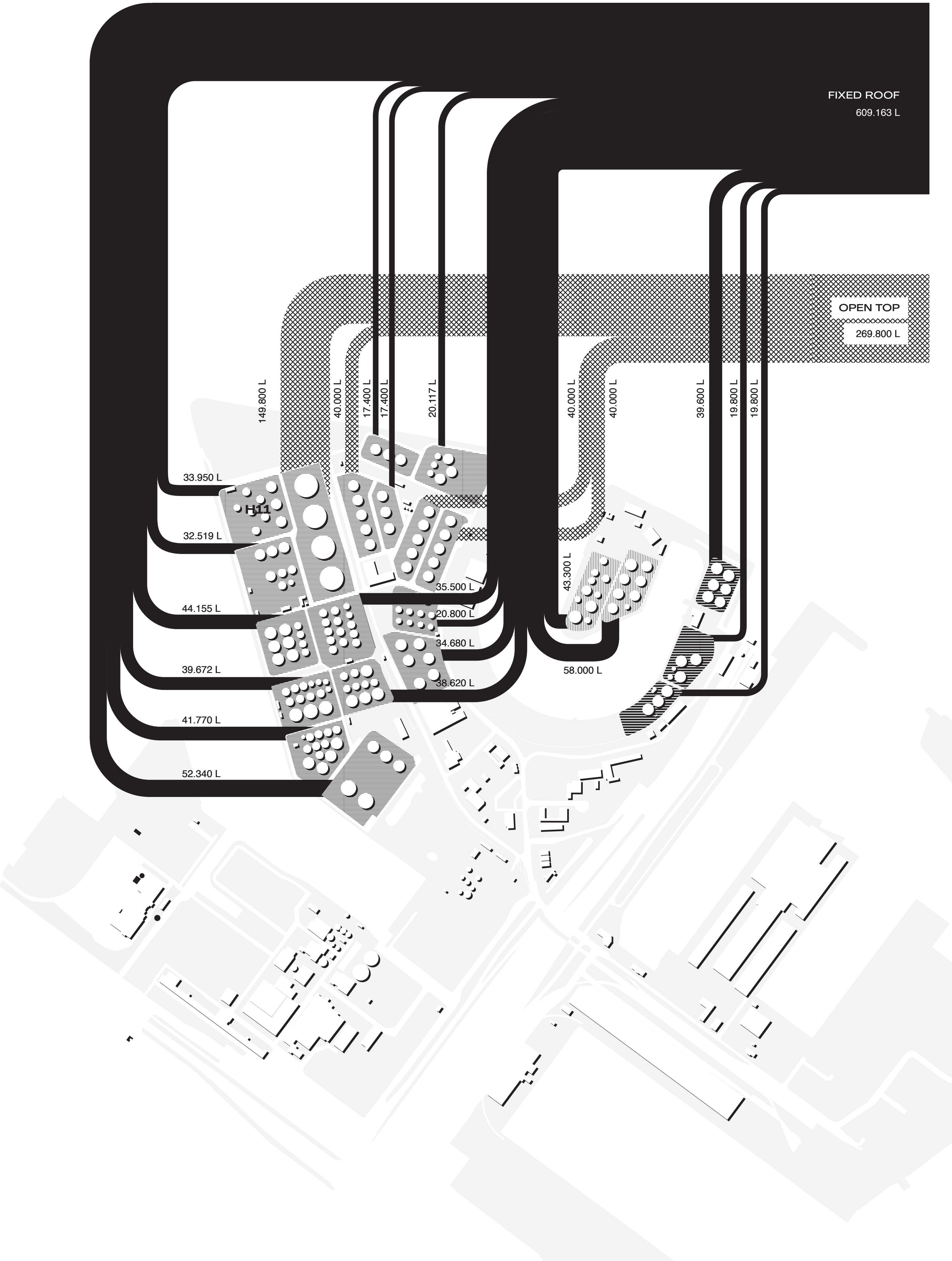
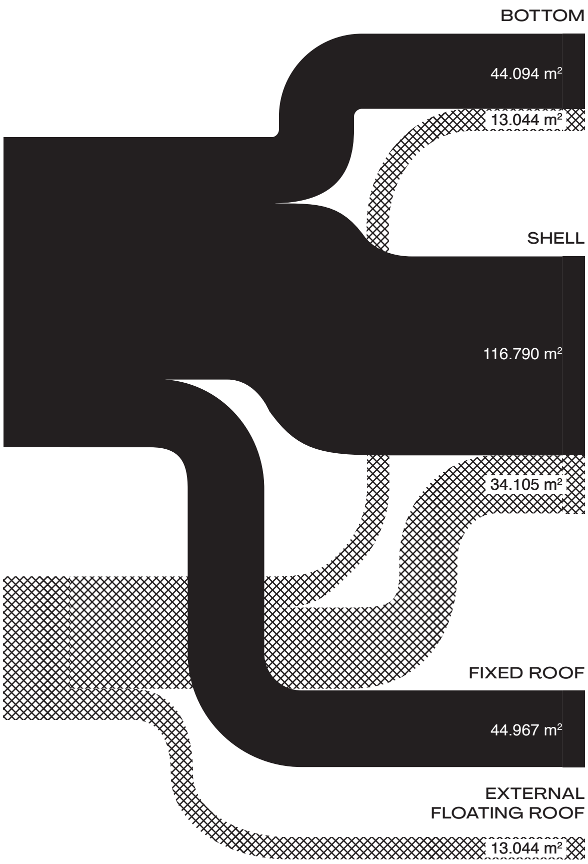
Appendix A

Material Flow Analysis





57.138 m^2

Carbon steel welded plates
Thickness 5-9 mm

150.895 m^2

Carbon steel welded plates, bended in tank-radius
Thickness 5-9 mm

44.967 m^2

Carbon steel welded plates
Thickness 5-9 mm

13.044 m^2

Floating double-layered sandwich panels

FIXED ROOF
GIRDERS

44.339 m

Steel I-profiles
Size up to IPE400

Appendix B

Data and calculations (used for MFA)

Company	Class	Put	Tank-ID	Tank-size (m3)	Ø tanks (m)	r tanks (m)	h tanks (m)	s walls (m2)	s EFR (m2)	s bottom (m2)	roof type	h cone (m)	slant h (m)	s cone (m2)	l beams (m)
						r = ø/2	h = V/(π*r^2)	S = 2*π*r*h	S = π*r^2	S = π*r^2		hc = r/5 (1:5)	sh = √ (r^2+hc^2)	S = π*r*sh	l = 32 * sh (average 32)
VTTI / ETA	K1	**H01**	H0101	37.450	48	24,0	20,7	3.121	1.810	1.810	EFR				
			H0102	37.450	48	24,0	20,7	3.121	1.810	1.810	EFR				
<u>Sources used:</u>			H0103	37.450	48	24,0	20,7	3.121	1.810	1.810	EFR				
diameter: plan VTTI/ETA			H0104	37.450	48	24,0	20,7	3.121	1.810	1.810	EFR				
volume: plan VTTI/ETA				**149.800**				**12.483**	**7.238**	**7.238**					
	K3	**H03**	H0376	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0377	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0378	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0379	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0380	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0381	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0382	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0383	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0384	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0385	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0386	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0387	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0388	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0389	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
				35.500				**8.889**		**2.785**				**2.840**	**3.622**
	K3	**H04**	H0415	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0416	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0417	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H0418	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0419	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H0420	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0421	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H0422	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H0423	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H0424	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
				38.620				**7.698**		**3.025**				**3.085**	**3.133**
	K3	**H11**	H1191	-											
			H1192	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H1193	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H1194	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H1195	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H1196	3.250	18	9,0	12,8	722		254	Coned	1,8	9,18	260	293,7
			H1197	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H1198	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H1199	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6

Company	Class	Put	Tank-ID	Tank-size (m3)	Ø tanks (m)	r tanks (m)	h tanks (m)	s walls (m2)	s EFR (m2)	s bottom (m2)	roof type	h cone (m)	slant h (m)	s cone (m2)	l beams (m)
						r = ø/2	h = V/(π*r^2)	S = 2*π*r*h	S = π*r^2	S = π*r^2		hc = r/5 (1:5)	sh = √(r^2+hc^2)	S = π*r*sh	l = 32 * sh (average 32)
				33.590				**6.501**		**2.630**				**2.682**	**2.643**
	K3	H12	H1216	3.054	18	9,0	12,0	679		254	Coned	1,8	9,18	260	293,7
			H1217	2.120	14,6	7,3	12,7	581		167	Coned	1,46	7,44	171	238,2
			H1218	5.069	21,6	10,8	13,8	939		366	Coned	2,16	11,01	374	352,4
			H1219	3.505	17,8	8,9	14,1	788		249	Coned	1,78	9,08	254	290,4
			H1220	3.055	18	9,0	12,0	679		254	Coned	1,8	9,18	260	293,7
			H1225	5.183	23,4	11,7	12,1	886		430	Coned	2,34	11,93	439	381,8
			H1226	5.168	23,6	11,8	11,8	876		437	Coned	2,36	12,03	446	385,1
			H1227	5.175	23,3	11,7	12,1	888		426	Coned	2,33	11,88	435	380,2
			H1228	190	6	3,0	6,7	127		28	Coned	0,6	3,06	29	97,9
				32.519				**6.442**		**2.614**				**2.666**	**2.713**
	K3	H13	H1343	5.839	24	12,0	12,9	973		452	Coned	2,4	12,24	461	391,6
			H1344	5.836	24	12,0	12,9	973		452	Coned	2,4	12,24	461	391,6
			H1345	5.861	24	12,0	13,0	977		452	Coned	2,4	12,24	461	391,6
			H1346	5.846	24	12,0	12,9	974		452	Coned	2,4	12,24	461	391,6
			H1347	5.860	24	12,0	13,0	977		452	Coned	2,4	12,24	461	391,6
			H1348	5.847	24	12,0	12,9	975		452	Coned	2,4	12,24	461	391,6
			H1349	2.266	15	7,5	12,8	604		177	Coned	1,5	7,65	180	244,8
			H1350	2.271	15	7,5	12,9	606		177	Coned	1,5	7,65	180	244,8
			H1351	2.256	15	7,5	12,8	602		177	Coned	1,5	7,65	180	244,8
			H1352	2.273	15	7,5	12,9	606		177	Coned	1,5	7,65	180	244,8
			H1353	200											
				44.155				**8.266**		**3.421**				**3.489**	**3.329**
	K3	H14	H1401	7.270	27,6	13,8	12,2	1.054		598	Coned	2,76	14,07	610	450,3
			H1402	7.269	28	14,0	11,8	1.038		616	Coned	2,8	14,28	628	456,9
			H1403	7.256	28	14,0	11,8	1.037		616	Coned	2,8	14,28	628	456,9
			H1404	2.561	18	9,0	10,1	569		254	Coned	1,8	9,18	260	293,7
			H1405	1.548	14,3	7,2	9,6	433		161	Coned	1,43	7,29	164	233,3
			H1406	2.573	18	9,0	10,1	572		254	Coned	1,8	9,18	260	293,7
			H1407	1.536	14,3	7,2	9,6	430		161	Coned	1,43	7,29	164	233,3
			H1408	2.258	18	9,0	8,9	502		254	Coned	1,8	9,18	260	293,7
			H1409	1.547	14,3	7,2	9,6	433		161	Coned	1,43	7,29	164	233,3
			H1410	2.531	18	9,0	9,9	562		254	Coned	1,8	9,18	260	293,7
			H1411	1.132	12	6,0	10,0	377		113	Coned	1,2	6,12	115	195,8
			H1412	529	10,2	5,1	6,5	207		82	Coned	1,02	5,20	83	166,4
			H1413	1.135	12	6,0	10,0	378		113	Coned	1,2	6,12	115	195,8
			H1414	527	10,2	5,1	6,4	207		82	Coned	1,02	5,20	83	166,4
				39.672				**7.799**		**3.719**				**3.793**	**3.963**
	K2/K3	H21	H2106	150											

Company	Class	Put	Tank-ID	Tank-size (m3)	Ø tanks (m)	r tanks (m)	h tanks (m)	s walls (m2)	s EFR (m2)	s bottom (m2)	roof type	h cone (m)	slant h (m)	s cone (m2)	l beams (m)
						r = ø/2	h = V/(π*r^2)	S = 2*π*r*h	S = π*r^2	S = π*r^2		hc = r/5 (1:5)	sh = √(r^2+hc^2)	S = π*r*sh	l = 32 * sh (average 32)
			H2108	500											
			H2164	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2165	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H2166	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2167	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2168	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2169	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2170	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2171	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2172	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H2173	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H2174	2.250	15	7,5	12,7	600		177	Coned	1,5	7,65	180	244,8
			H2175	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
				41.770				**8.653**		**3.223**				**3.287**	**3.524**
	K3	H22	H2201	17.500	30,9	15,5	23,3	2.265		750	Coned	3,09	15,76	765	504,2
			H2202	17.500	30,9	15,5	23,3	2.265		750	Coned	3,09	15,76	765	504,2
			H2257	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H2259	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
			H2261	5.780	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
				52.340				**7.421**		**2.857**				**2.914**	**2.183**
	K1	H43	H4301	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4302	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4303	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4304	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4305	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4306	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4307	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4308	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4309	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
			H4310	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
				80.000				**14.414**	**3.871**	**3.871**					
	K3	H53	H5301	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5302	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5303	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5304	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5305	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5306	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5307	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5308	1.850	14	7,0	12,0	529		154	Coned	1,4	7,14	157	228,4
			H5309	2.300	18,6	9,3	8,5	495		272	Coned	1,86	9,48	277	303,5

Company	Class	Put	Tank-ID	Tank-size (m3)	Ø tanks (m)	r tanks (m)	h tanks (m)	s walls (m2)	s EFR (m2)	s bottom (m2)	roof type	h cone (m)	slant h (m)	s cone (m2)	l beams (m)
						r = ø/2	h = V/(π*r^2)	S = 2*π*r*h	S = π*r^2	S = π*r^2		hc = r/5 (1:5)	sh = √ (r^2+hc^2)	S = π*r*sh	l = 32 * sh (average 32)
			H5310	3.700	19,9	10,0	11,9	744		311	Coned	1,99	10,15	317	324,7
				20.800				**5.467**		**1.814**				**1.850**	**2.456**
	K3	**H63**	H6324	4.066	21	10,5	11,7	774		346	Coned	2,1	10,71	353	342,7
			H6325	4.061	20,9	10,5	11,8	777		343	Coned	2,09	10,66	350	341,0
			H6329	2.076	15	7,5	11,7	554		177	Coned	1,5	7,65	180	244,8
			H6330	2.061	15	7,5	11,7	550		177	Coned	1,5	7,65	180	244,8
			H6331	2.075	15	7,5	11,7	553		177	Coned	1,5	7,65	180	244,8
			H6333	5.778	24	12,0	12,8	963		452	Coned	2,4	12,24	461	391,6
				20.117				**4.171**		**1.672**				**1.705**	**1.810**
	K3	**H73**	H7334	5.788	24	12,0	12,8	965		452	Coned	2,4	12,24	461	391,6
			H7339	5.815	24	12,0	12,9	969		452	Coned	2,4	12,24	461	391,6
			H7341	5.811	24	12,0	12,8	969		452	Coned	2,4	12,24	461	391,6
				17.414				**2.902**		**1.357**				**1.384**	**1.175**
	K3	**H83**	H8301	5.783	24	12,0	12,8	964		452	Coned	2,4	12,24	461	391,6
	K1		H8302	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
	K3		H8303	5.800	24	12,0	12,8	967		452	Coned	2,4	12,24	461	391,6
	K1		H8304	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
	K3		H8305	5.803	24	12,0	12,8	967		452	Coned	2,4	12,24	461	391,6
	K1		H8306	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
	K1		H8308	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
	K1		H8310	8.000	22,2	11,1	20,7	1.441	387	387	EFR				
				57.386				**10.105**	**1.935**	**3.293**				**1.384**	**1.175**
	K2	**H93**	H9301	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
	K2		H9302	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
	K2		H9303	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
	K2		H9304	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
	K2		H9305	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
	K2		H9306	5.780	24	12,0	12,8	963		452	EFR	2,4	12,24	461	391,6
				34.680				**5.780**		**2.714**				**2.768**	**2.350**
		Total VTTI / ETA		**698.363**	m3		Total surface area	**116.991**	**13.044**	**46.233**				**33.846**	**34.076**
Alkion	K3	**ALK-1**	Alk1	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
			Alk2	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
Sources used:			Alk3	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
height: AHN (2020)			Alk4	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
diameter: TOP10NL			Alk5	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
volume: website Alkion			Alk6	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
				39.600				**6.336**		**2.945**				**3.004**	**2.448**

Company	Class	Put	Tank-ID	Tank-size (m3)	Ø tanks (m)	r tanks (m)	h tanks (m)	s walls (m2)	s EFR (m2)	s bottom (m2)	roof type	h cone (m)	slant h (m)	s cone (m2)	l beams (m)
						r = ø/2	h = V/(π*r^2)	S = 2*π*r*h	S = π*r^2	S = π*r^2		hc = r/5 (1:5)	sh = √ (r^2+hc^2)	S = π*r*sh	l = 32 * sh (average 32)
	K3	**ALK-2**	Alk7	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
			Alk8	6.600	28	14,0	10,7	943		616	Coned	2,8	14,28	628	456,9
			Alk9	6.600	28	14,0	10,7	943		616	Coned	2,8	14,28	628	456,9
				19.800				**2.942**		**1.722**				**1.756**	**1.322**
	K3	**ALK-3**	Alk10	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
			Alk11	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
			Alk12	6.600	25	12,5	13,4	1.056		491	Coned	2,5	12,75	501	407,9
				19.800				**3.168**		**1.473**				**1.502**	**1.224**
		Total Alkion		**79.200**			Total surface area	**12.446**		**6.140**				**6.262**	**4.993**
MAIN	K1/K2/K3	**MAIN-1**	M101	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
			M102	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
Sources used:			M103	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
height: AHN (2020)			M104	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
diameter: TOP10NL			M105	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
			M106	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
			M107	8.000	20	10,0	25,5	1.600		314	Coned	2	10,20	320	326,3
			M108	2.000	10	5,0	25,5	800		79	Coned	1	5,10	80	163,2
				58.000				**12.000**		**2.278**				**2.323**	**2.448**
	K3	**MAIN-2**	M201	10.000	25	12,5	20,4	1.600		491	Coned	2,5	12,75	501	407,9
			M202	2.500	13,5	6,8	17,5	741		143	Coned	1,35	6,88	146	220,3
			M203	2.200	13,5	6,8	15,4	652		143	Coned	1,35	6,88	146	220,3
			M204	7.000	24,5	12,3	14,8	1.143		471	Coned	2,45	12,49	481	399,8
			M205	4.800	20	10,0	15,3	960		314	Coned	2	10,20	320	326,3
			M206	2.500	13,5	6,8	17,5	741		143	Coned	1,35	6,88	146	220,3
			M207	2.700	15	7,5	15,3	720		177	Coned	1,5	7,65	180	244,8
			M208	2.700	15	7,5	15,3	720		177	Coned	1,5	7,65	180	244,8
			M209	4.500	16,5	8,3	21,0	1.091		214	Coned	1,65	8,41	218	269,2
			M210	4.500	16,5	8,3	21,0	1.091		214	Coned	1,65	8,41	218	269,2
				43.400				**9.458**		**2.487**				**2.536**	**2.823**
		Total MAIN		**101.400**				**21.458**		**4.765**				**4.859**	**5.270**
		Total		**878.963**				**150.895**	**13.044**	**57.138**				**44.967**	**44.339**
		Total fixed		609.163				116.790	-	44.094				44.967	44.339
		Total open top		269.800				34.105	13.044	13.044				-	-