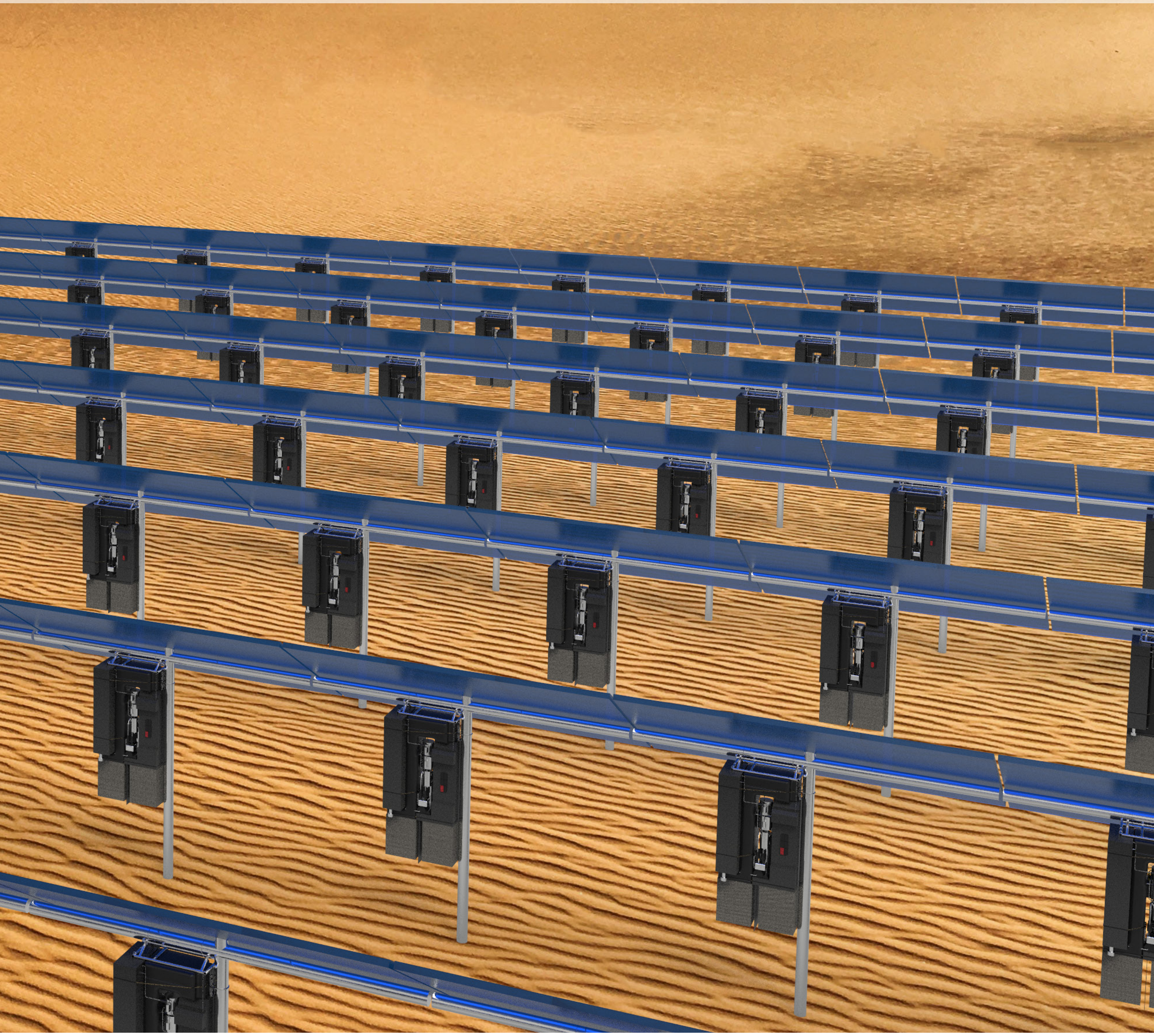
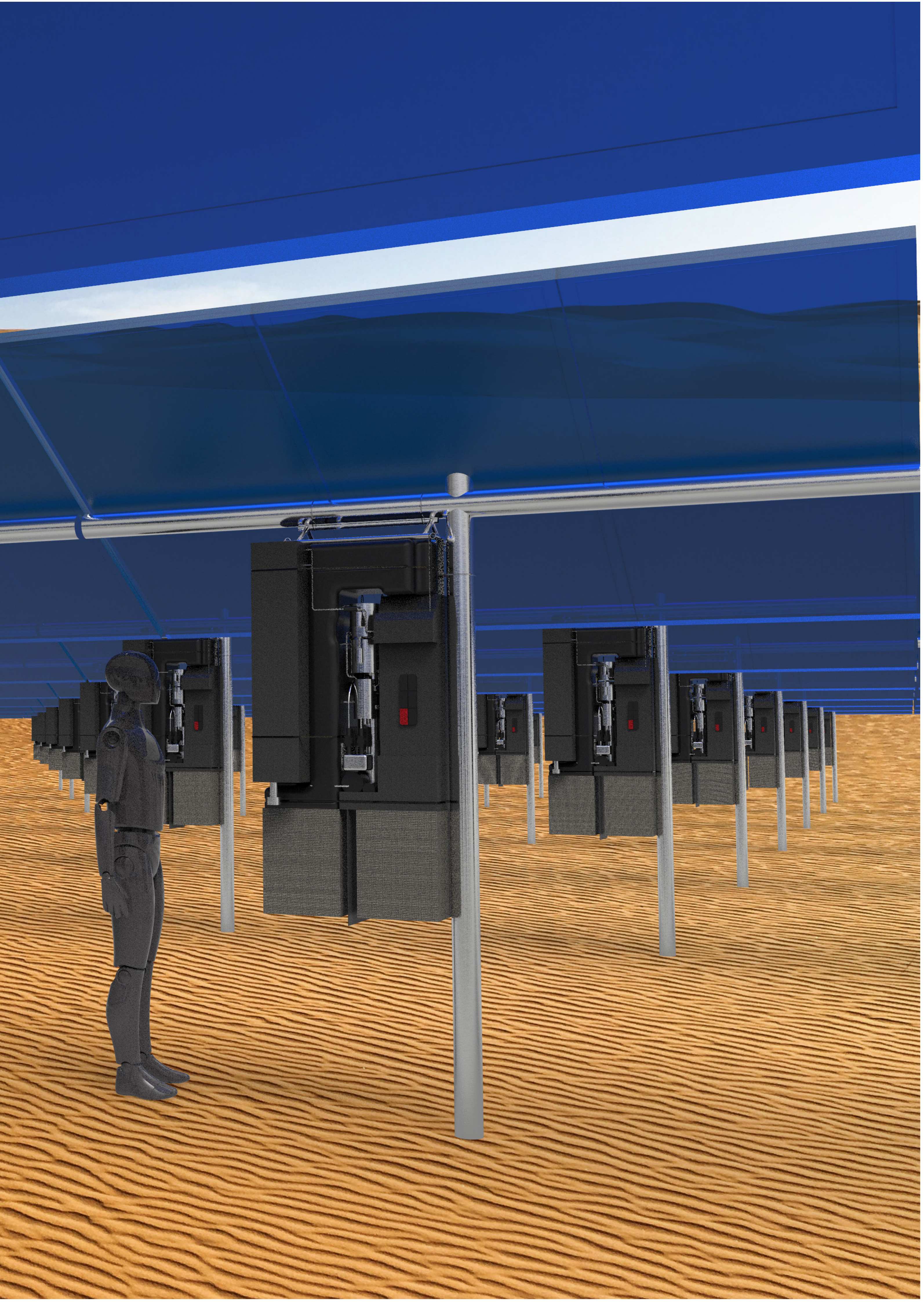
# Methanol from sunlight and air: A guide towards the embodiment design of the micro plant



Graduation Report - Gerianne Boer





# Methanol from sunlight and air: A guide towards the embodiment design of the micro plant

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Februari 2020 - August 2020

# Executive summary

The carbon emission of fossil fuels contributes to global warming. The start-up ZEF develops a sustainable alternative to create fuel. By capturing CO2 and H2O from the air, the energy from PV solar panels, and the right technology, they create methanol. Methanol can, among other things, be used as a fuel or to create plastics. This product is called a micro plant. With the development of large PV solar farms with 40.000 solar panels and 13.000 micro plants, methanol will be produced on a large scale.

The micro plant is a small chemical factory with about 50 different parts. These parts are individually, or within one of the four subsystems developed at TRL level 4. However, these parts are only developed at a technical level; the integration of these parts into a micro plant suitable for the mass manufacturing of 100,000 pieces has had little thought. Therefore the purpose of this graduation project is to guide ZEF towards an embodiment design for the micro plant. The four main design drivers that influenced the choices are price, functionality, environmental impact, and flexibility.

To get to an embodiment design the influence of maintenance, the architecture design, the insulation and the casing where researched.

**Maintenance**: The micro plant requires maintenance about every 2 to 5 years. The chosen maintenance strategy is preventive predetermined scheduled maintenance. The two extreme options for maintenance were maintenance at the micro plant's location or automated maintenance in a garage. Option one was chosen because this allows for the flexibility to make changes in the maintenance schedule. This resulted in the requirement to have access to all maintenance interfaces and six control buttons for the micro plant.

**Architecture design:** Architecture design is about how the different parts are positioned relative to each other. Size of the parts, their heat and cooling requirements, their maintenance requirements, and their place in the system diagram determined their position.

**Insulation:** The material used for insulation is stone wool. Stone wool is cheap, durable, and has the proper thermal properties. It can be manufactured in different ways; for this project, the solution of a box made with stone wool plates, placed around the insulation parts and filled with stone wool flakes will be used. The insulation gets a plastic protective layer.

**Casing:** The core function of a casing is to keep all the parts stiff together and transport the air from the air filter to the air fan. It is unnecessary to have a casing that encloses the whole micro plant because most parts do not require an enclosed to ensure a 20 years lifetime. This design chooses a blow-molded air duct with a steel frame to embody this 'naked' casing.

In the end, the total costs of the micro plant where higher than expected. The micro plant needs to be suitable for more PV solar panels, cheaper, or it is not feasible.

This project was only a starting point for product design, recommend is to continue the development on the product level, because the product level does influence the technical level. Also, getting from a concept to a product requires time and collaboration with multiple stakeholders.



# Preface

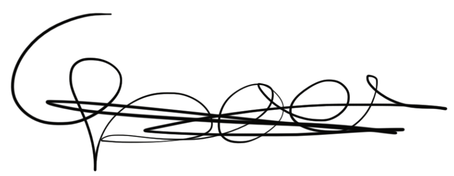
Dear reader,

When I first contacted ZEF in September 2019, I immediately felt enthusiastic, a real challenge with a technical aspect in it, and even more critical working on innovation with the ambition to have a positive environmental impact. After an internship in Nepal, half a year later, in February 2020, I could start, and I wrote my master thesis: 'a guide toward the embodiment design of the micro plant.' With this thesis, I graduated from the master 'Integrated Product Design' at the TU Delft, and I become a Master of Science.

Only after a month of working at ZEF the Netherlands had to get into an intelligent lockdown, due to the outbreak of COVID-19. For me, this mends that I had to work from home, among other things, I missed the small coffee breaks with my colleagues and the motivating work environment at ZEF. Working from home, I felt like I could achieve less work, and it felt less satisfying. But I also was happy that I had a goal to work on during this lockdown.
Now another half a year later, in August 2020, I am almost finished. I can say I enjoyed working on the project. I am left with a result I feel proud of and a great learning experience.

I want to thank ZEF and especially Jan, for always answering my questions, and bringing lots of positive energy about the project. But of course also Hessel and Ulrich and all the others working at ZEF for their input and team feeling. Secondly, I want to thank my graduation committee, JC, for all your enthusiasm and Jos for your input on the project. I also and want to thank Henria, Manon, and Wilfried for checking some of my content. And of course, I also want to thank my family and friends for their love and support.
I hope you enjoy opening this report!

Cheers,



Gerianne Boer
Delft, august 2020.

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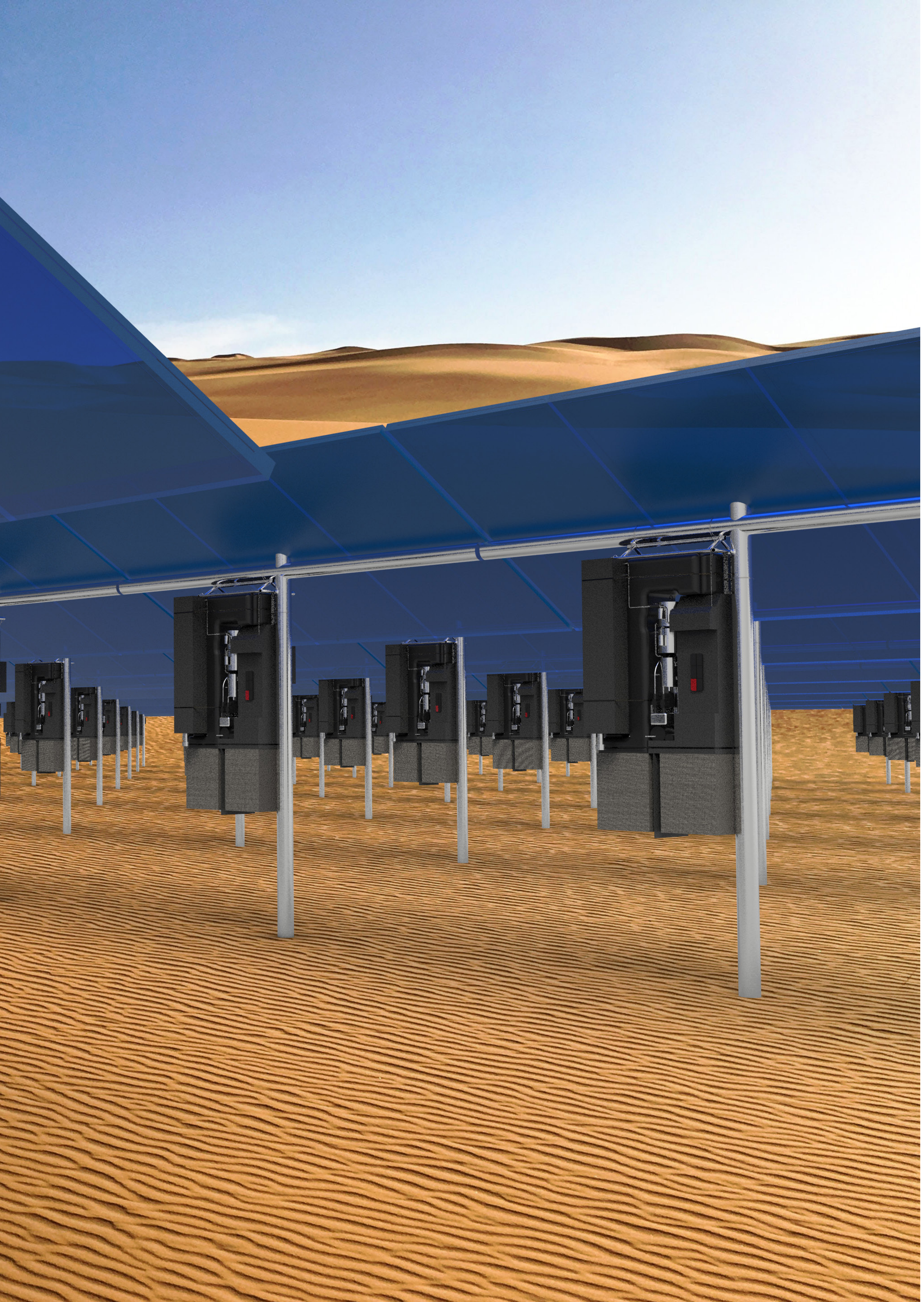
Appendix



# Legenda

In the whole report, the same colors are used to indicate subsystems within figures.

**DAC:** Direct Air Capture

**FM:** Fluid Machinery

**AEC:** Alkaline Electrolytic Cell

**MS:** Methanol Synthesis

# 1. Introduction

This report will provide insights into the product development of a methanol producing micro plant. The micro plant is developed by a Dutch start-up, ZEF (Zero Emission Fuels). The micro plant captures CO2 and H2O from the air. Together with the electricity generated by PV solar panels, the micro plant creates methanol. This methanol is sustainable because the CO2 is captured from the air and does not use fossil fuels for its creation.

First, the broader context and relevance of the project will be described. During the exploration phase, the project scope will be explored. This is concluded by a synthesis including a problem statement research objectives, selection criterium, and a program of requirements. Two concepts will be used as a starting point for the design. Throughout various iterations and the answering of research questions, the design evolves into a full embodiment design for the micro plant. The report ends with recommendations to proceed with the product development of the micro plant.

## 1.1 Context

The world's atmosphere is changing at a rapid pace, since the start of the industrial revolution, the concentration of CO2 has increased by more than a third (National Aeronautics and Space Administration (NASA, n.d.). A cause of this is the burning of fossil fuels, like oil, gas, and coal. The increase of CO2 affects the greenhouse effect, which is held responsible for global warming.

To stop global warming, humans have to decrease the the volume of greenhouse gases emitted into the atmosphere. Sustainable solutions to fulfill the energy demand have to be found.  At the same time, the global energy demand is still growing (Enerdata, N.D..-a). Only a small part of the energy consumed is electricity (Enerdata, N.D..-b). So there is not only a need for renewable electricity solutions like PV solar panels (figure 1.2) but a demand for renewable fuel solutions, too.

Developing these renewable fuel solutions can contribute to sustainable development, which is widely formulated as:
*''Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. (Brundtland, Khalid, Agnelli, Al-Athel, & Chidzero 1987).''*

## 1.2 Methanol

Methanol is chosen as the fuel that will be produced by ZEF. This is because methanol is the simplest alcohol with the lowest carbon content and the highest hydrogen content. Secondly, because methanol is a building block for hundreds of essential commodities and can be used as fuel too, for example, power vehicles or produce plastics.

each micro plant will produce 600 grams of methanol a day, assuming it is attached to 3 PV solar panels and gets 8 hours of sun a day.



The chemical formula of methanol is CH3OH. Methanol is a colorless liquid. It boils at 65 degrees Celsius and freezes at-94 degrees Celsius. It is dangerous for humans to consume methanol (Petruzzello, n.d.).
Conventional ways of producing methanol require the use of gas or coal. This happens in large chemical plants (figure 1.1). One plant can produce 5,000 ton methanol a day (Methanol Institute, 2020). The development of these large chemical plants takes a long time, lots of $CO_2$ emissions, and requires high investments.

Figure 1.1 International Methanol Company. (n.d.).

## 1.3 ZEF

ZEF stands for Zero Emission Fuels. It is the name of a start-up,– aiming to develop a micro plant that can produce methanol with the electricity from PV (Photovoltaic) solar panels and CO2 and water from the air. The company mainly employs graduate students and interns that join a team for half a year.
This assignment is executed during the 6th team. Team 6 consists out of 33 students and four people responsible for the management at ZEF. The whole team is divided into sub-teams. Each sub-team is responsible for a subsystem. The company works with a tight budget and is based inside the 3mE faculty of the TU Delft. ZEF also cooperates with graduates that work on an individual assignment.

Figure 1.2  PV solar panels (Photo by Science in HD on Unsplash)

# 1.4 Project focus

**Technology road map:** The micro plant consists of different subsystems that are still under development. Figure 1.3 illustrates a technology road map of ZEF.
At the technology level, all the subsystems are conceptualized. Optimization of the subsystems is under development.
This graduation uses the information on the technology level to develop the micro plant at a product level. It is relevant to start thinking of the product level of the micro plant before the subsystems are fully defined because the technology level influences the product level, but the product level can also influence the technology level. Furthermore, the deadline for product development is coming closer.

**Scope:** The scope is the starting point for exploring relevant subjects that influence the embodiment design of the micro plant. Figure 1.4 illustrates the full scope of the graduation project. ZEF is in a stage where some of these aspects are designed and researched in depth. For example, the design of the subsystems. Other aspects, like the maintenance of the micro plant, are only researched at a surface level.

The scope can be illustrated with an example of the architecture design of a car. The designer needs some information about the motor, like volume and interactions with other elements in the car. Nevertheless, she does not need to know all the details about how the motor works on the inside. In the example, the motor is within the scope, but the exact details are not within the scope. This also counts for this graduation project. All the subsystems are within the scope, but only the details that influence the embodiment design of the micro plant will be described.
Furthermore, the project will be forked from most of the developments at ZEF. The project will gather information on the technology level at the beginning of the project. Technology developments after this point are not always part of the project scope.

**TRL:** Figure 1.5 illustrates the TRL (technology readiness level) of different subsystems,

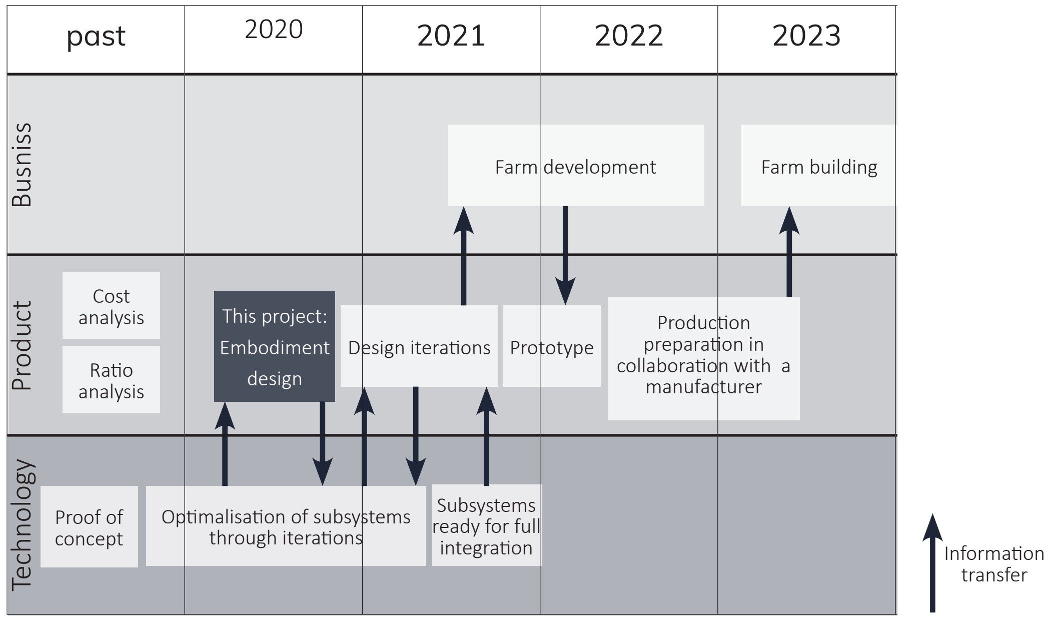



Figure 1.3 Technology road map



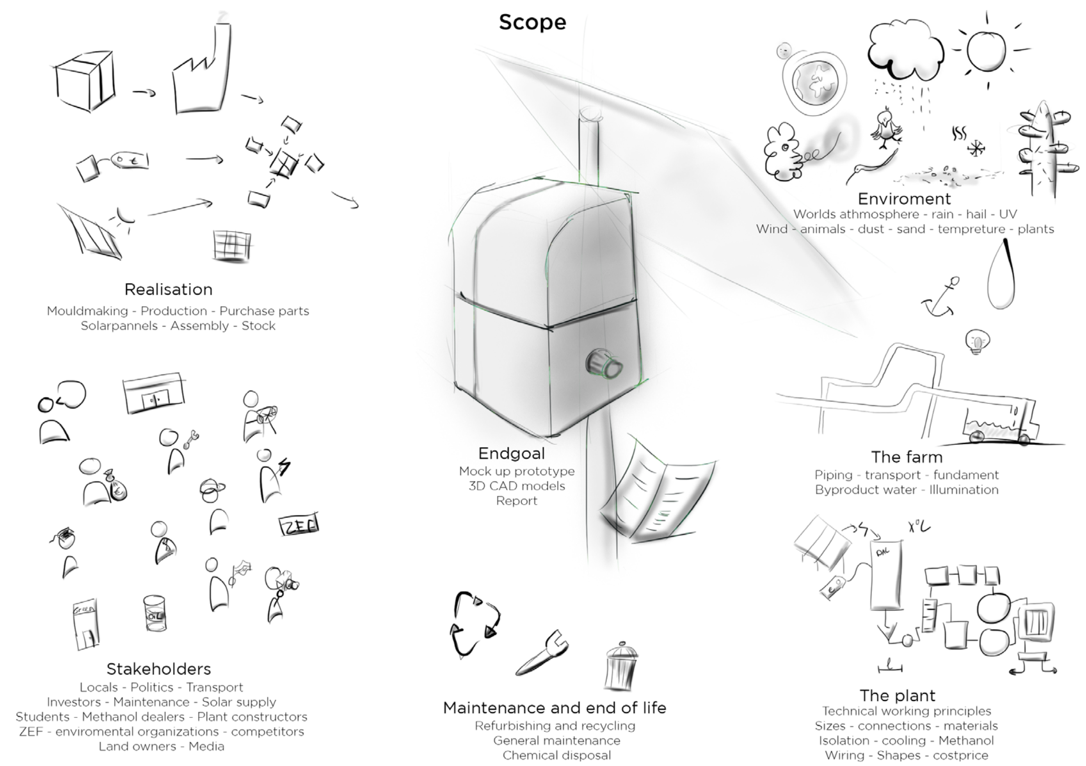



Figure 1.4 Brainstorm about the scope of this graduation project.

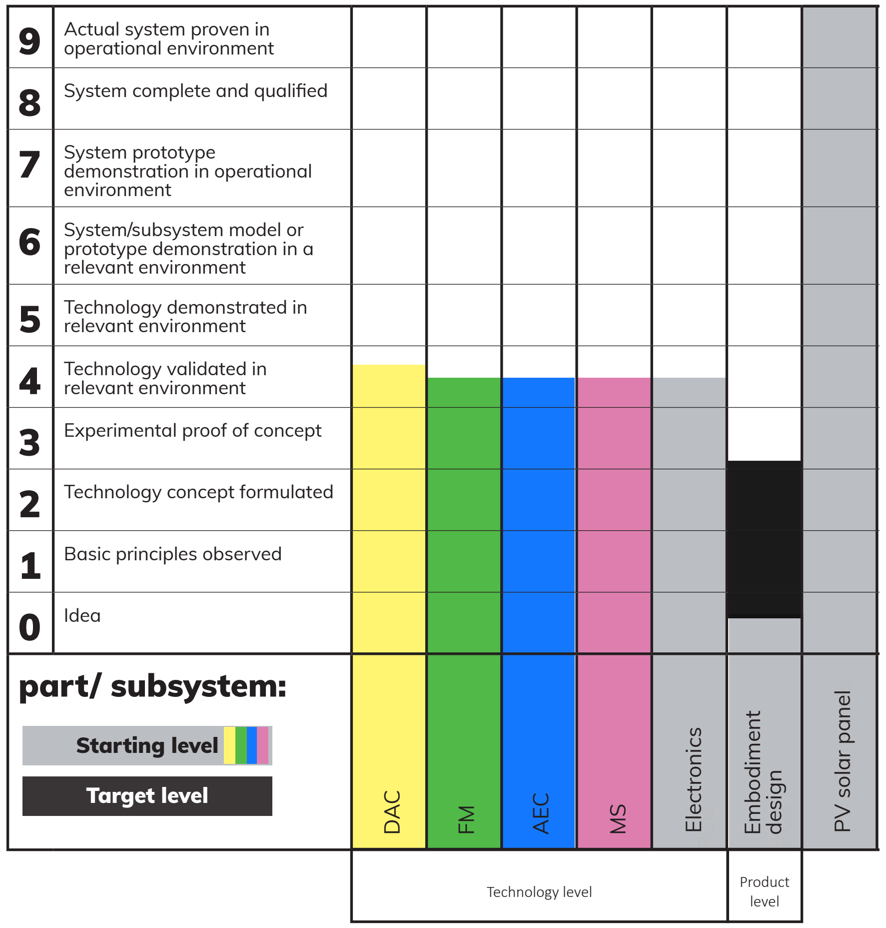



Figure 1.5 Technology readiness level

parts, and embodiment design. It illustrates the start of the project and in red what will be done during this project. The embodiment design lags behind the subsystems that are on a technical level because it is not possible during this project to make a full-scale functional prototype of the embodiment, because of manufacturing limitations and subsystems still being in the test setup, not ready for integration on a prototype level.

## 1.5 Goal

The goal of this report is:

"To guide ZEF by illustrating design options regarding maintenance, heat and cooling efficiency, assembly and casing design, and the relative influence on the price of the methanol produced by the micro plant. Resulting in an embodiment design for the micro plant, without the technological details of the subsystems. This result will be expressed by a non- functional physical prototype to inspire, educate & display a vision for the end micro plant."

**Guiding:** provides a framework of the design limitations, formulating design challenges, exploring the options, and formulating selection criteria to make a validated design choice.

**Embodiment design: :** is offering a concrete form to a concept. It is a follow up of the concept design phase and is succeeded by the detailed design phase within the process**.**

Figure 1.6 illustrates the purpose of building a non-functional physical prototype.

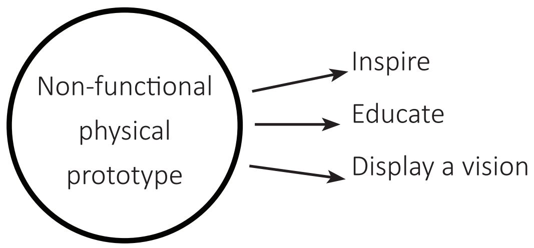



Figure 1.6 Purpose of a non-functional physical prototype

This report is not a fixed explanation of how the design should be implemented. The report is structured in a way that supports design modifications to stay relevant even when the optimization of the technology requires changes in the design.

## 1.6 Approach

Different models can be used as a guideline. Figure 1.7 illustrates a typical 'stage-gate' model where a fixed result is required to enter to the next phase. Each separated phase consists of a converging and a diverging part. The illustration is adapted to the context and goal of this project. A more agile and innovative model is Evans's model (Geissdoerfer, Savaget, & Evans, 2017). The paper provides a new approach to the development of sustainable business models. The general stage-gate model The



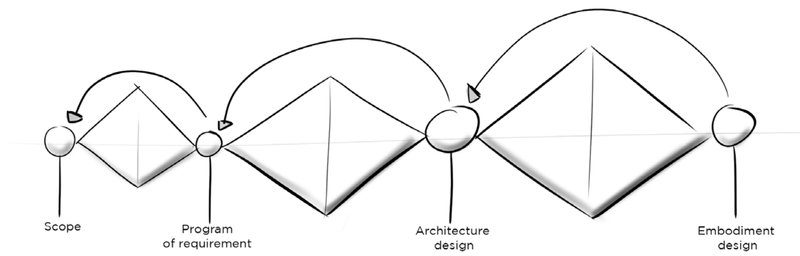



Figure 1.7 A stage-gate model applied to this project

cycle consists of eight sequential but iterative phases. This means that one can go back and forth in the phases and repeat one or several phases. The whole model can be repeated endlessly. Although the model is designed to develop sustainable business models, it can still guide the complex process of creating a product architecture and embodiment design. This model is chosen because the context of the project is still evolving. A fixed result from one stage will still change over time. Therefore a more holistic approach is needed to see this project as a developing design rather than a fixed parameter. Therefore, both models will be used as a guideline to create a holistic approach.

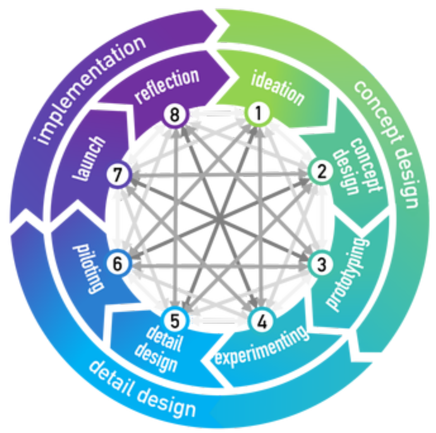



Figure 1.8 Business model innovation process (Evans et al, 2017)

## Key takeaways

- **It is an ambitious project, innovative in technology, and the approach to solving the problem.**
- **Innovation in technology can be seen in the approach to make methanol from sunlight and air—Furthermore, the approach to use mass manufacturing methods to create a competitive business case.**
- **The approach to solving the problem is innovative because ZEF works with students and a tight budget resulting in a dynamic work environment.**
- **This project adds value by guiding towards an embodiment design. This embodiment design is a way to communicate design guidelines and considerations.**
- **This project is executed while the technology is still at TRL level 4, meaning that it is not fully defined yet.**
- **The designer works with an iterative approach with multiple converging and diverging moments.**

# 2. Exploration

This chapter provides background information that is used as a starting point to compile a problem statement, research objectives, research questions, design guidelines, and a program of requirements.

## 2.1 The micro plant

The product works with 6 different subsystems. Figure 2.1 illustrates a schematic overview of the system.

**DAC: Direct Air Capture**

The DAC captures $CO_2$ and water from the air.

**FM: Fluid Machinery**

The FM compresses the $CO_2$ from 0.1 to 50-60 bar. It also seperates the $CO_2$ from the leftover $H_2O$ in the system.

**AEC: Alkaline Electrolytic Cell**

The AEC electrolyzes the $H_2O$ to form $O_2$ and $H_2$. It stores the $H_2$ and releases the $O_2$. It also purifies the water from the $CO_2$ that is still left in the water.

**MS: Methanol Synthesis**

Inside the MS the following reactions will take place:

$CO_2 + 3H_2$ <--> $CH_3OH + H_2O$

$CO_2 + H_2$ <--> $H_2O + CO$

The end product of the MS is a mixture of $CH_3OH$ (methanol) and $H_2O$.

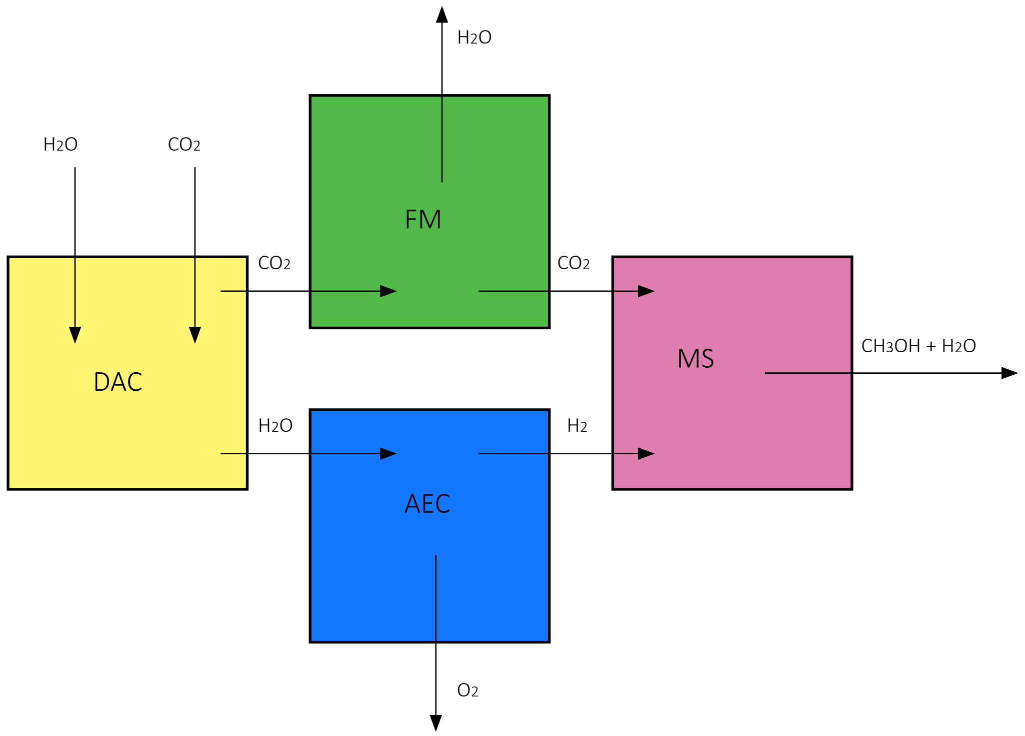



Figure 2.1: Schematic overview of the plant



**DS: Distillation system:** The distillation system separates the methanol from the water. The result is 99.8% pure methanol (grade A) and water. The distillation proces can take place in the micro plant itself or outside the micro plant on a centralized place at the farm. For this project, it is assumed that the distillation system is not inside the micro plant.

**PV solar panels:** Every micro plant will be attached to one up to ten PV solar panels. The type of PV solar panel to be used is not defined yet. The PV solar panel is most likely a purchased part that will be chosen at the time of realization based on the market prices and performance of the PV solar panels. It is assumed that the PV solar panel racks contain vertical beams to the ground. If necessary the micro plant can be attached to these beams.

It is assumed that no battery or converter needs to be part of the micro plant.

Furthermore it is assumed that the lifetime of the micro plant should be at least 20 years. The 20 years is based on the estimated lifetime of a PV solar panel.

## 2.2 Stakeholders

Figure 2.2 illustrates the major part of the stakeholders that are involved with the development of the micro plant and it's future success.

Figure 2.3 illustrates some of the more significant stakeholders. These stakeholders are categorized by the amount of influence and interest they have in the embodiment and architecture design of the micro plant. Not all stakeholders have a direct influence on the architecture and embodiment design. Stakeholders that could have a direct influence on the embodiment design or the goal of this project will be described underneath. Other relevant stakeholders are described in appendix A.

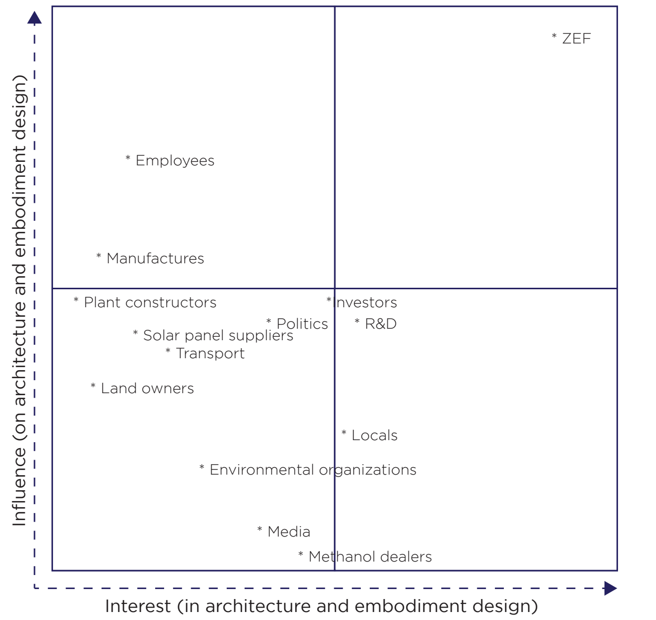



Figure 2.2 Stakeholders matrix

*Note: Although stakeholders might influence the embodiment design of the micro plant, the main design drivers will be functionality and price.*

**Locals:** Locals are the people that live in the surrounding areas of the methanol farm. Locals can have an interest because of job opportunities. They might also be affected

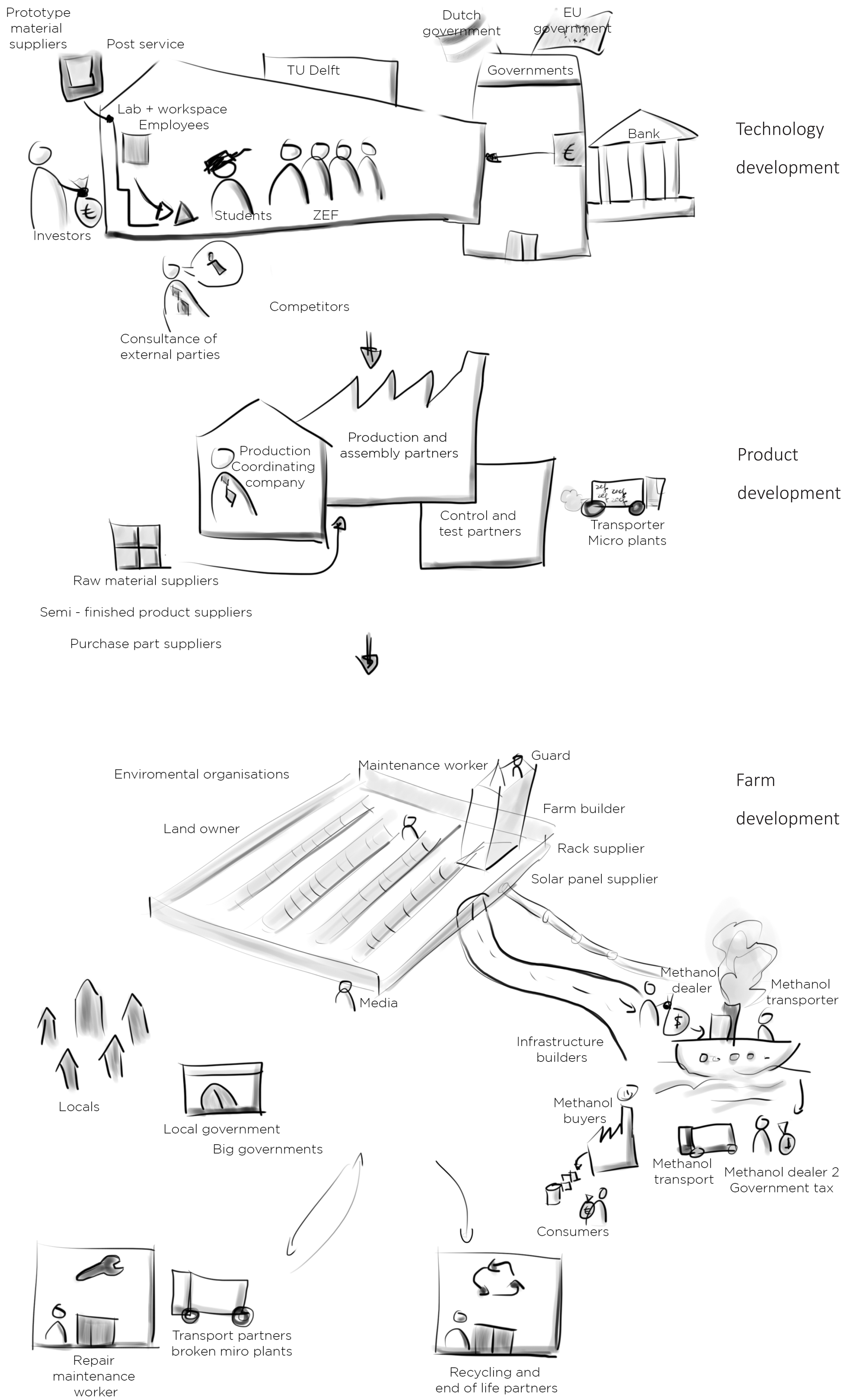



Figure 2.3 Selected stakeholders overview



by the realisation of new infrastructure. Locals and farm employees might become subject to noise produced by the farm. A noise level of 80 decibel for more than 8 hours can cause hearing damage; more decibel require a shorter exposure. An exposure exceeding 20 decibel can cause direct harm (Ear check 2015). The noise created by the micro plant will be restricted to periods of sun hours. The locals might also be interested in the safety of the farm; if something goes wrong, they might be directly affected.

It is assumed that fences, camera's and guards will sufficiently protect the methanol farm. In politically unstable countries or regions additional security measures might be added (ZEF, 2019). For now, it is assumed that the micro plant itself does not need to be designed to be protected from vandalism or theft.

**Employees:** assumed is that ZEF will work with low-educated employees that will do maintenance work on the farm and highly educated employees that will repair and evaluate broken micro plants. The employee will have an interest in risks related to the safety of the micro plant and the ease of their job.

**Maintenance employees:** a maintenance employee should be able to safely access the micro plant. Therefore, the micro plant should be assembled at an altitude accessible for the employees. It is assumed that maintenance employees will earn minimum wages. This is mainly due to the expected lack of relevant educational background. Specialized training for the maintenance employees prior to employment at the micro plant has been taken into account. Employment at the micro plant requires at least a basic understanding of the English language.The maintenance employees will do the necessary work regarding the maintenance. The maintenance employees will not open the micro plant for safety purposes; they will access the parts that are designed to access during use. Methanol is highly flammable. If the micro plant stops working, it is dangerous to open the micro plant. When something in the micro plant breaks, a signal will alert the maintenance employee that something is wrong. The maintenance employee will detach the methanol/water piping and swap the micro plant for a working one.
The quicker/ easier the repair employee can do her job, the lower the cost.

**Repair employees:** The repair employee will have a good understanding of English and is trained to analyze and repair the micro plant. The high skilled employee does want to do her job efficiently in a safe way.

**ZEF:** For ZEF, the cost and the function are way more important than the actual look of the micro plant. However, an honest look can help to attract investors and communicates a positive message to other stakeholders.

**Manufactures:** The capacity of production techniques, the will to cooperate with ZEF, and the price of the manufacturing could all influence the embodiment design of the micro plant.

## 2.3 Farm

Photo Credit: East Pecos Solar 120MW$_{AC}$, Texas, Southern Power

Figure 2.4 Solar farm

The farm is not engineered and designed jet. Engineering will most likely be done in cooperation with a PV solar panel provider, farm builder, or both parties. Large PV solar panel farms already exist (figure 2.4). The difference with these power farms is that there are no inverters in the methanol farm, but micro plants instead. Inverters convert the direct current from a PV solar panel into utility frequency alternating current that can be fed to the electricity grid (Wik.ipedia contributors, 2020). Assumed is that there is a ratio of 10 PV solar panels per micro plant. Figure 25 illustrates how a future farm assumed to look.

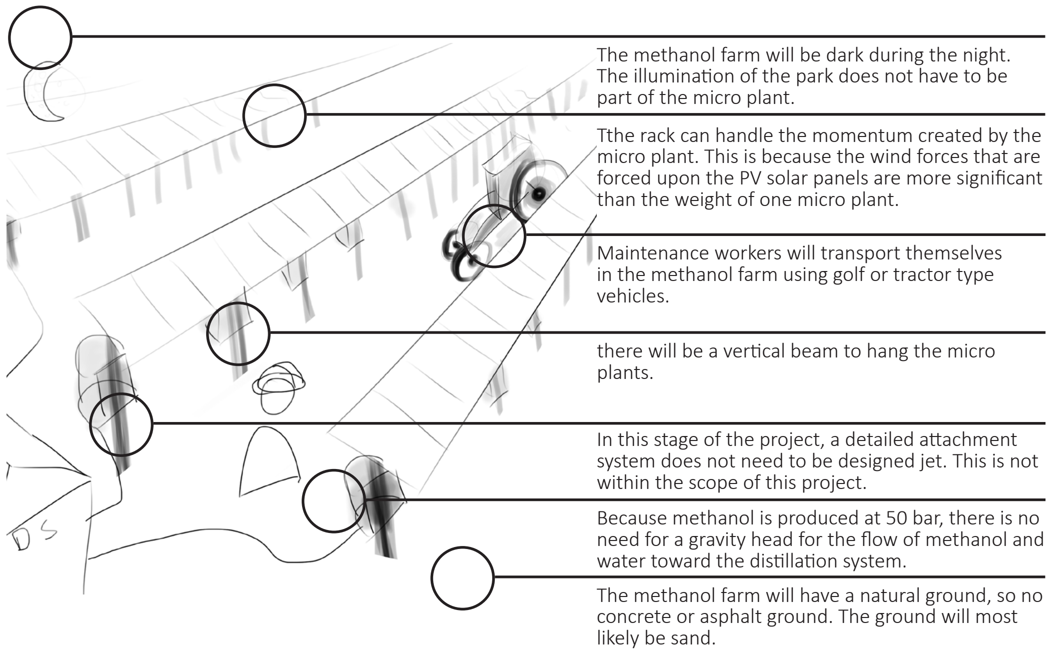



Figure 2.4 Solar farm



## 2.4 Location

Figure 2.6 Sandstorm (Garcia, 2005).

The location of the farm determines the er mate the micro plant needs to withstand. The climate is relevant because it determines which environmental factors the micro plant needs to withstand.

Location selection: According to a study by, ZEF (Buijtenweg, van Rooi, Vendrik, Verhoeven, & Volberda, 2019), Moquegua in Peru is the optimal location. The report illustrates that small changes in assumptions or data can change the optimal location choice. The optimal location is the location where ZEF can produce the lowest price per ton of methanol. The optimal location was chosen from 21 countries with:

- Enough sun
- Politically stable
- An abundance of space.

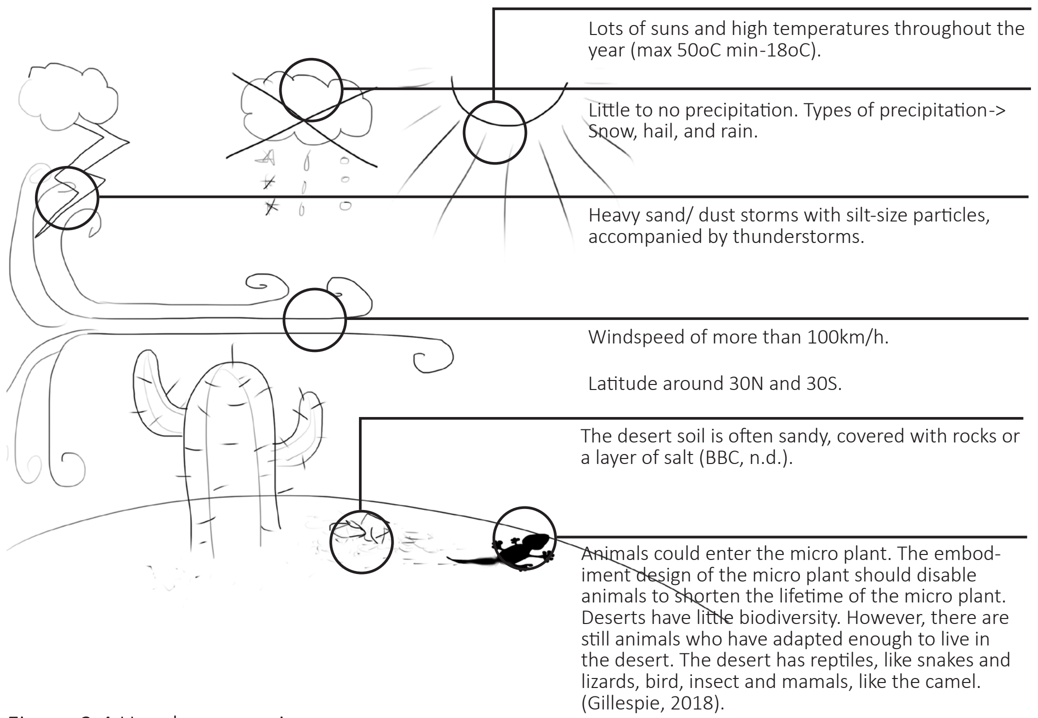



Figure 2.4 Hot desert enviroment

If the first farm is a success, more farms will be realized. These new farms will be built on the same or at different locations. The uncertainty of the current location and the future perspective means that the micro plant should withstand all weather conditions, plants, and wildlife that can be found on any of the potential locations.
The farm will be built in areas with much sunlight. Most of these areas are classified as hot or cold deserts. The hot desert usually has a more extreme climate than the cold desert. Therefore the scope of this research is the extremes from the hot desert.

**Weather conditions:** A climate is called a desert when there is low precipitation, usually not more than 200mm annually. The characteristics of a hot desert are illustrated in figure 2.7 (Hays, 2011; Junior, 2017; Miller, 2017; Windfinder, n.d.) Figure 2.6 illustrates how a sandstorm can look like.

## 2.5 Production

Assumed is that the micro plant will be produced in Europe. The purchased parts and the PV solar panel will be bought at a low price, most likely from China.
The assembly should happen most economically and could be done by robots or by hand. For assembly with robots, an experienced company can be contracted. Before using micro plants, quality control can be executed.

It is desirable to have an embodiment design suitable for all the farms that will be built in the first seven years after the realization of the first farm. Table 2.1 illustrates the production volume.

| | |
|---|---|
| Assumed batch size | 100,000 micro plants |
| Size first test farm before starting mass production | 40.000 PV solar panels |
| PV solar panels per micro plant | 3 |
| Amount of micro plants in first test farm | 13.000 micro plants |

Table 2.1 Production volume

## 2.6 Environmental impact

Once installed and fully operational the micro plant will have a positive impact on the environment by capturing CO2 from the air. CO2 will released into the air as soon as the methanol is burned. Methanol produced by the micro plant will have a positive impact on the environment. Nevertheless, the materials used and the production of the micro plant could still harm the environment.
A study (ZEF, & Hacking, 2019) was conducted to investigate the total impact of the micro plant. The study found that the net impact of the micro plant is positive. It outlines the following recommendations to further minimize the environmental impact:

- Maximize the efficiency of the micro plant.
- A long lifetime is vital to reduce environmental impact, therefore lifetime is more important than the materials used.
- Recycling will decrease environmental impact.



**Lifetime:** In the event of breakage the broken micro plant will be sent to the Netherlands where it will be analysed. It is essential to know what has caused the breakage in order to predict the possible failure of other micro plants and to redesign new genera¬tions of micro plants. Before sending the micro plant back to the farm, the micro plant can be tested in a controlled environment.

Failure of the micro plant is more likely to happen particularly in moving parts; these are the com¬pressors in the FM and the pressure relief valves. Failure also can occur inside the electronica and sensors.

The outline of the circular economy, as illustrated by the Ellen MacArthur Foundation (n.d.), can be used as a guide to minimize environmental impact. By circulating products and materials and using renewable energy a circular economy can be achieved.

**End of life:** End of life covers all further steps to be taken with the micro plant after the end of its lifetime, considering that it cannot be maintained any longer, re-used or refurbished anymore. End of life still continues the environmental impact of the micro plant. However, the amount of methanol that can be produced as well as the lifetime of the micro plant are vital factors in decision making. End of life should not be considered with high priority. An ideal scenario for the end of life could be the moment when the micro plant is disassembled. If possible, parts will be re-used or refurbished. From all parts, the exact composition of the materials is known, the different component materials can easily be separated and recycled. The use of non-recyclable and toxic materials should be avoided if possible.

## 2.7 Financing

The final goal is not to make the cost price of the micro plant as low as possible but to make the price per ton of methanol as low as possible. Figure 2.8 illustrates how different aspects of embodiment design of the micro plant can influence the methanol price. Several aspects influence the methanol price in different ways. CapEx is the capital expenditure for the farm. This mainly covers the farm infra¬structure and the hardware costs of the micro plant. The micro plant costs form a large share of the total cost of methanol (Buijtenweg, et al., 2019). OpEx are the operational expenses of the farm. For example: the costs of maintenance. Lifetime indicates how long the micro plant and the farm can fulfil their function. If the lifetime is shortened from 20 to 10 years, the CapEx has twice as much influence on the price of methanol. The illustration provides an idea about how different aspects influence the price of the methanol produced by the micro plant. It is used to illustrate how design choices can influence the methanol price in different ways. Furthermore, the realization of a methanol farm requires capital. This capital could, for example, be obtained from investors or subsidies. This graduation project can make the setup of a micro plant less abstract and more appealing for investors.

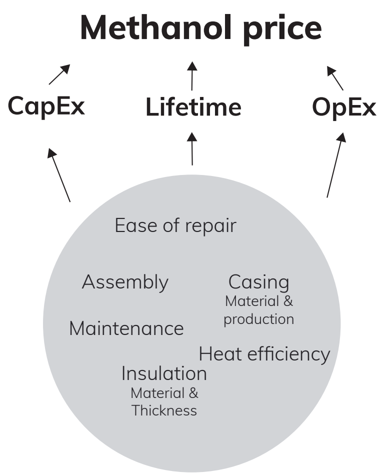



Figure 2.8 Methanol price

## Key takeaways

- The DAC, FM, AEC, and MS need integration into one mass-producible micro plant.
- The exploration point out the following points essential for the embodiment design of the micro plant:
    - The micro plant needs to survive 20 years in hot dessert circumstances.
    - The batch size is 100.000 pieces.
    - The micro plant should have a positive environmental impact. This can be done with the sustainable production of methanol, the design for a long lifetime of the micro plant, and the ability to recycle materials.
- ZEF is involved with a large number of stakeholders. Stakeholders that influence or could be influenced by the embodiment design of the micro plant are relevant.
- Although the context is not 100% clear, yet the context will be frozen to design appropriately.



# 3. Synthesis

This chapter synthesizes insights from the previous chapters to create a framework for this graduation project. Figure 3.1 illustrates the structure of this chapter.

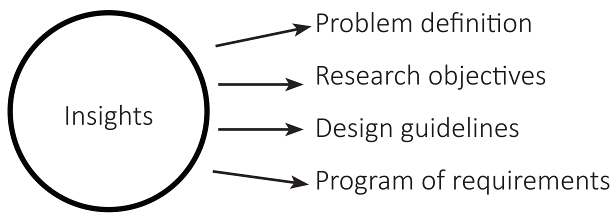



Figure 3.1 Synthesis structure

**Problem definition:** What problems does this project solve?

**Research objectives:** The main goal is divided into multiple smaller goals (research objectives) and research questions.

**Design guidelines:** Guide validated choices between the options that come across during a divering phase.

**Program of requirements**: The program of requirements gives a set of boundaries. Everything not applicable within these boundaries is either not suitable for the design or it expresses that something initially went wrong with formulating the program of requirements. The final program of requirements can be found in appendix B.

Figure 3.2 illustrates an analogy of how the synthesis will guide. The problem definition indicates why we should go in a certain direction. The objectives are 'stopovers' to gather the right information necessary to reach the main goal. The program of requirements will indicate where I can ´walk´ and were not; it indicates the boundaries. The selection criteria will guide me to find the best 'path' to achieve the main goal.

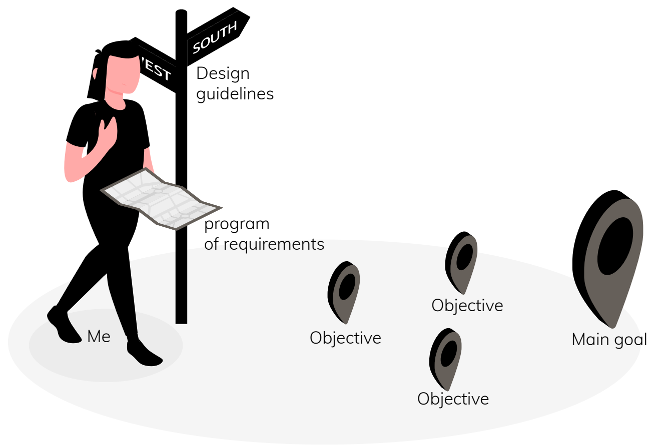



Figure 3.2 Synthesis

## 3.1 Problem definition

To achieve the goal of ZEF ‘to produce methanol from the air with large solar farms’ advanced technology is under development. However, this technology should be developed into a micro plant that can be mass-manufactured and should be operational for at least 20 years.

**Parts:** There should be an overview of all the parts needed and the requirements of these individual parts to get to an architectural design. In addition an overview is required of how these parts interact together. It is a challenge to filter out the information that is relevant for the embodiment design but also to have a complete overview in place disregarding unnecessary details.

**Architecture design:** It needs to be established in what sequential order parts can be integrated most optimally. To create an efficient heat optimization plan is another challenge. Some parts need to be cooled while other parts need insulation. This will affect the architecture design of the micro plant. The micro plant requires regular maintenance. The frequency of the maintenance and detailed activities are not clear, yet. It needs some efforts to predict how the optimal maintenance scenario will look like in the future and how this will influence the architectural design of the micro plant. The different parts need to be assembled. There should be enough stiffness to prevent failure in the future. It is a challenge to find out in what way this can be realized effectively.

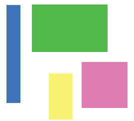
**Casing:** The micro plant needs to perform under afore mentioned extreme desert circumstances. Insulation needs to be kept together while some parts need protection. It is a challenge to design a casing that will turn out to be less costly but still fulfils its core functions.

## 3.2 Research objectives

The research objectives are divided into two objectives: the different parts of the design (parts) and their underlying relations (architecture design) and the casing around these parts (casing). To get to an embodiment design first the parts need to be described. Secondly the architectural design needs to be determined. Therefore, different factors influencing the architecture design will have to be researched. The factors are heat and cooling efficiency, maintenance and assembly. Finally, by researching the core functions and limitations of the casing its properties and shape can be determined.

The description of part properties can be found in appendix C.



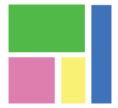


### Parts

**Objective:** To describe the relevant properties and interactions of the parts within the micro plant that contribute to embodiment design.

**Research questions:**

1. What are the relevant properties for the parts within the micro plant?

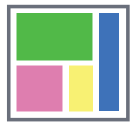


### Architecture design

**Objective**: To integrate all parts optimally.

**Research questions:**

1. How do heat and cooling efficiency influence the architecture design ?
2. How will the optimal maintenance journey effect the design of the micro plant?
3. What are the most important considerations for assembly and how does this effect the architecture design of the micro plant?



### Casing

**Objective:** To design a casing that can fulfil its core functions.

**Research questions:**

1. How do heat and cooling efficiency influence insulation?
2. What are the core functions and limitations of the casing?
3. What are the micro plant properties and the main shape of the casing?

## 3.3 Design guidelines

**The main design guideline is the influence on the price of the methanol, produced by the micro plant.**
The micro plant is only feasible if it can produce methanol for a competitive price. A number of different factors influencing this price need to be considered. Sub chapter 2.7 illustrates the complexity of this methanol price structure. As the methanol price is complicated most design decisions will have to be based on assumptions about the methanol price and factors that contribute to this price.

The design guidelines are:

- **Price:** The influence on the price of the methanol produced by the micro plant. Influence on the CapEx, the Opex, and the lifetime. In this phase of the design, how does the decision influence the part price for a batch size of 100.000 micro plants?
- **Functionality:**
  - Manufacturability: Can the embodiment design be produced for the intended batch size with manufacturing limitations of the chosen production method? Is there a need for secondary processes? Can the embodiment design easily be assembled?
  - Purpose: Can the intented production method fullfill the intended functions?
- **Environmental impact:** The core working principle of the micro plant is sustainable. The embodiment design will not change the core principle of the micro plant. However, if there are two choices equally influencing the methanol price of the micro plant the most sustainable solution should be chosen. Options should also be recyclable after 20 years lifetime .
- **Flexibility:** If the design decision is based on several assumptions how much flexibility is available for these assumptions to change? Does the choice allow iterations towards a better design in the future? How big are the investment costs: How big is the risk for ZEF?

**Key takeaways**

- **The main goal to get to an embodiment design has not changed. However, the path towards the embodiment design has been paved.**
- **The path follows the identification of parts, the integration of these parts, and the casing around these parts. During this process, heat and cooling efficiency, maintenance, and assembly will be taken into account.**
- **To steer towards the best result, the following design drivers will guide price, functionality, environmental impact, and flexibility.**



# 4. Maintenance

**Research question:** How will the optimal maintenance journey affect the design of the micro plant?

## 4.1 Introduction

**Maintenance definition:** Maintenance can be defined as:

"Combining all technical, administrative, and managerial actions during the lifecycle of an item intended to retain it in, or restore it to, a state in which it can perform the required function" (Peters & Madlener, 2017).

Within the micro plant, maintenance is essential to guarantee 20 years lifetime and to ensure that the micro plant will keep working optimally, meaning that a large quantity of MeOH is produced.

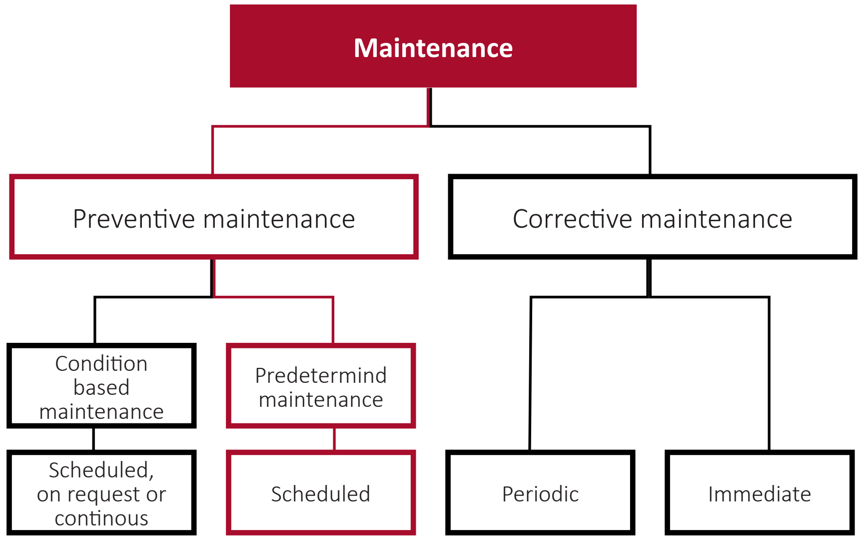



Figure 4.1 maintenance strategies (Peters & Madlener, 2017).

**Maintenance strategy:** Maintenance can be categorized into different subgroups (figure 4.1). Within this project, the choice is to use preventive, predetermined, scheduled maintenance.

Predetermined maintenance is first because of the redundancy strategy. When in a large chemical plant, one part fails, other parts can fulfill the same function, and not the whole chemical plant has to shut down. This is expensive because it requires multiple elements that can fulfill the same function. Moreover, sensors that can detect errors. In the case of the micro plant farm, the redundancy is not within the micro plant but in the number of micro plants fulfilling the same function. The CapEx of the micro plant needs to be minimal. Therefore the least amount of sensors will be used. If one sensor detects an error, the whole micro plant will shut down. Therefore, condition-based maintenance is not possible because there are no sensors or other ways to measure if maintenance is necessary. If the whole micro plant shuts down because of an error, it is not possible to predict the origin of the error, so the micro plant will need

to be repaired, this is a different procedure than maintenance.
Furthermore, the micro plant must keep producing a high amount of methanol; maintenance can increase the amount of methanol produced by the micro plant. It can be predicted when this maintenance is most effective, and therefore, it is predetermined maintenance. Predetermined maintenance also enables easier logistics for a large number of micro plants.

For the embodiment and maintenance design, maintenance employees should be able to see when the micro plant is not working anymore.

Within the scope of this research are all the parts that (might) require general preventive maintenance and the swapping of the micro plant. Not in this chapter are the general cleaning of the micro plant, the maintenance of the PV solar panels, the repair of broken micro plants, and the conservation of the farm area.

The chapter will give insights about maintenance on a top-level and on a part level. Promising solutions are clustered in a morphological chart. From this morphological chart, two concepts are generated. The concepts are compared, and the most promising concept is chosen.

**Maintenance timeline:** All the parts that require maintenance and their maintenance scenario are described in appendix D1-D7. Figure 4.2 provides an overview of these different parts and their assumed maintenance moment. The following conclusions can be derived from this graph:
- Maintenance is not a continuous process; it happens periodically.
- Different maintenance jobs can be combined or done during the same round.
- Sorbent maintenance might be done more frequently to create a more periodically maintenance scheme.

Swapping and oil wipe is in the schedule because the maintenance for these items should be predetermined, how often is dependent on design choices.

**Maintenance scenarios:** From the morphological chart in appendix D8, two maintenance scenarios are created.

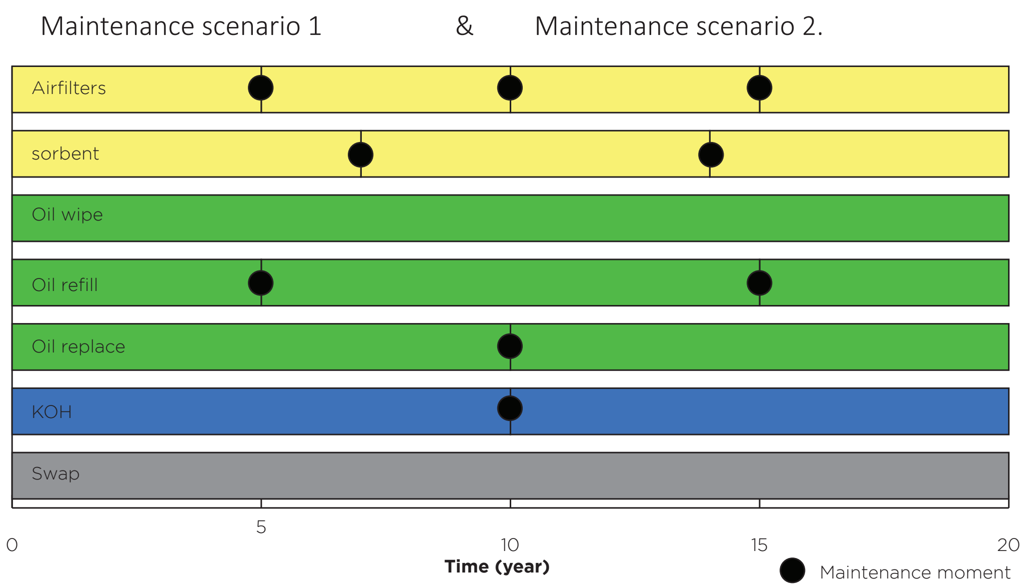



Figure 4.2 Maintenance timeline



The motivation to develop two significant different scenarios about maintenance is because it allows comparison between the scenarios. Also, because these are the two most realistic scenarios that fit a predetermined maintenance strategy, other maintenance scenarios are only possible if the predetermined maintenance would not be a binding factor.

**Scope:** The scenarios are developed on an abstract level. Only information that would be relevant for the comparison of the concepts is investigated. After comparing the scenarios, a choice will be made. The scenarios will be compared with as main goal to see if one scenario has a significant economic benefit over the other scenario. For this purpose, an economic model was created. Figure 4.3 illustrates the system boundaries of the economic model. It illustrates what is relevant to know when researching a maintenance scenario. Appendix D8 describes those that are used in the economic model.

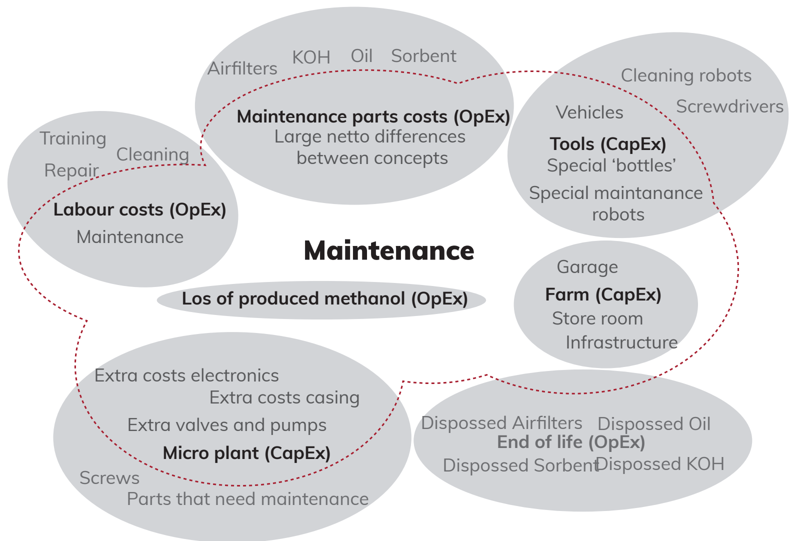



Figure 4.3 System bounderies maintenance scenarios

## 4.2 Maintenance scenario 1.

Scenario 1. has al its predetermined maintenance at the operating location of the micro plant. Assumed is that most maintenance does require manual labor and can not be fully automated with robots. It is assumed that most maintenance requires opening a cap to access the maintenance interface.

**Maintenance timeline**: Figure 4.4 illustrates the five maintenance moments that take place during 20 years lifetime. Assumed is that one maintenance moment has a deviation of half a year. So to complete one round of maintenance demands one year. For example, maintenance moment one will start at 4.5 years after operating the micro plant, and it finishes in year 5.5. The maintenance moments are not connected. In between the maintenance moments, there is a gap of 1.5 years where no maintenance is scheduled. There are two options, having a temporary team that comes

when maintenance is scheduled. Option two is to close the time gap. The gap can be closed by spreading the maintenance or by filling the gap with other activities, like conservation of the farm area and maintenance of PV solar panels. Assumed is that the maintenance tasks of one period will be joined. For example, during maintenance moment one, the maintenance employee will change the air filters and do the oil refill in one visit.
Sorbent maintenance is not synchronized with the other maintenance moments, because if that is done more Sorbent is needed, this will require more maintenance costs.

**Maintenance scenario:** Figure 4.5 illustrates the maintenance of maintenance moments 1, 3, and 5. Figure 4.6 illustrates the maintenance of maintenance moment 2 and 4. The time required to perform a task is an estimation.
For this scenario, it is assumed that the micro plant requires a casing and that it needs to open to access the maintenance parts.

**Maintenance costs:** Al the prices are prices that make this scenario different in price than the other concept. The prices are in euro per micro plant.
Plant costs:
Buttons and interfaces are all 1 euro per micro plant, based on the price of premanu-factured buttons (source)
Tool costs:
Robots that assist or do the maintenance are
the estimated price of a robot = 10000 for 20.000 micro plants, if maintenance is done for six micro plants a day for 300 days a year. Assumed is that there are 4000 micro plants on the farm. The price for the robot is based on a benchmark of similar high end automated robots, like milk robots and cheaper equipment like compres-sors.

The illustration shows that to design with this scenario, the CapEx costs are only increased by costs for the micro plant and costs for robots. The total CapEx costs are 4.50 euro.

This scenario influences the embodiment of the micro plant by allowing maintenance employees to easily access the parts that require maintenance and being able to assemble robots to these parts.

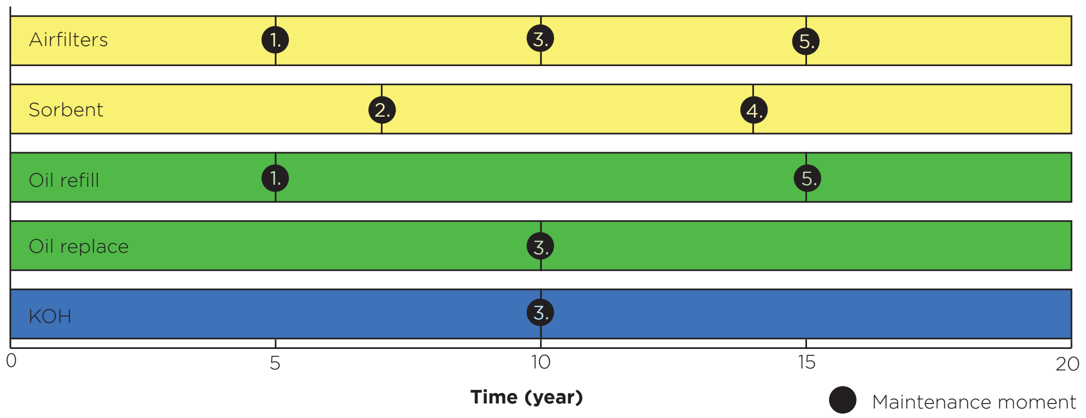
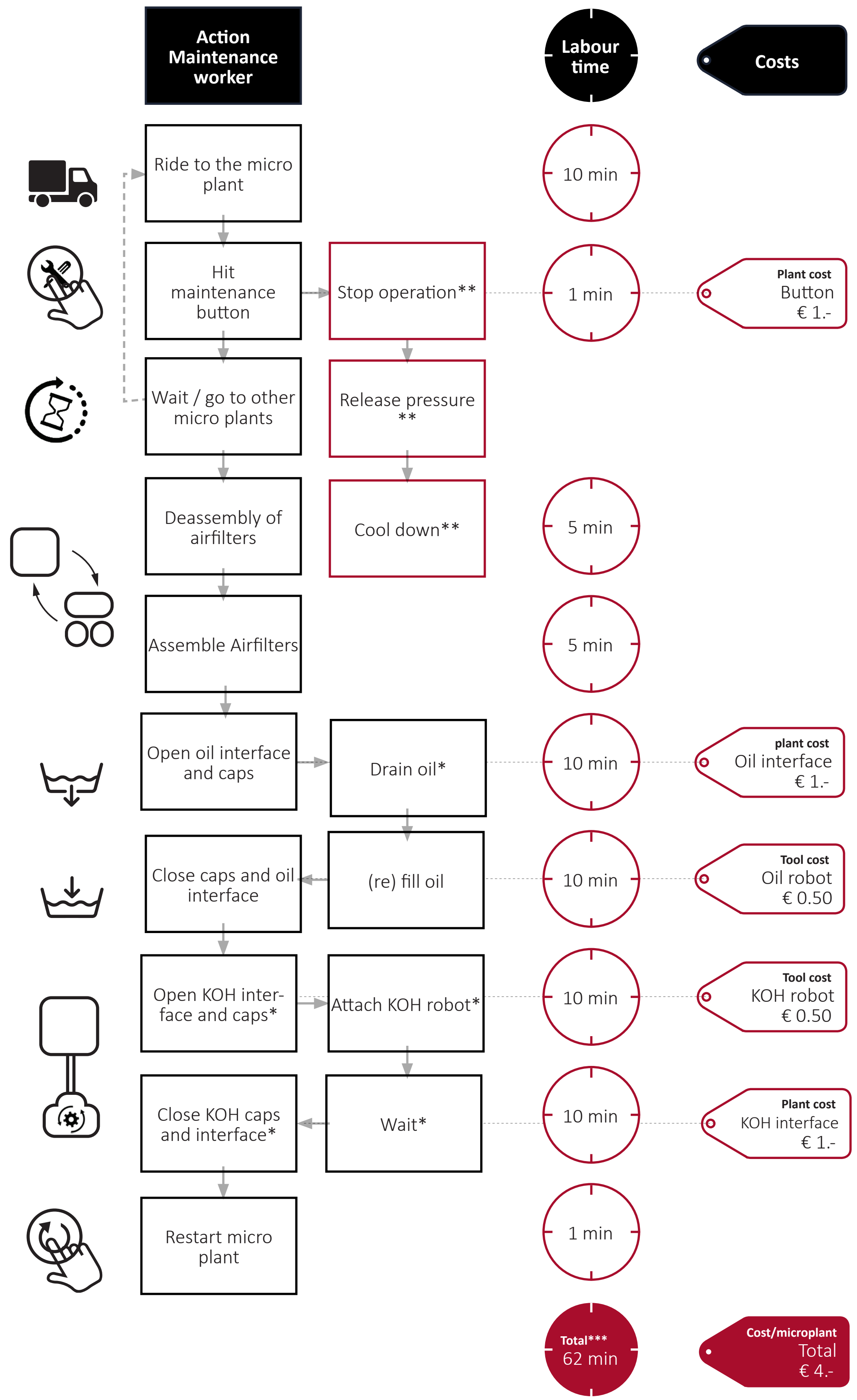


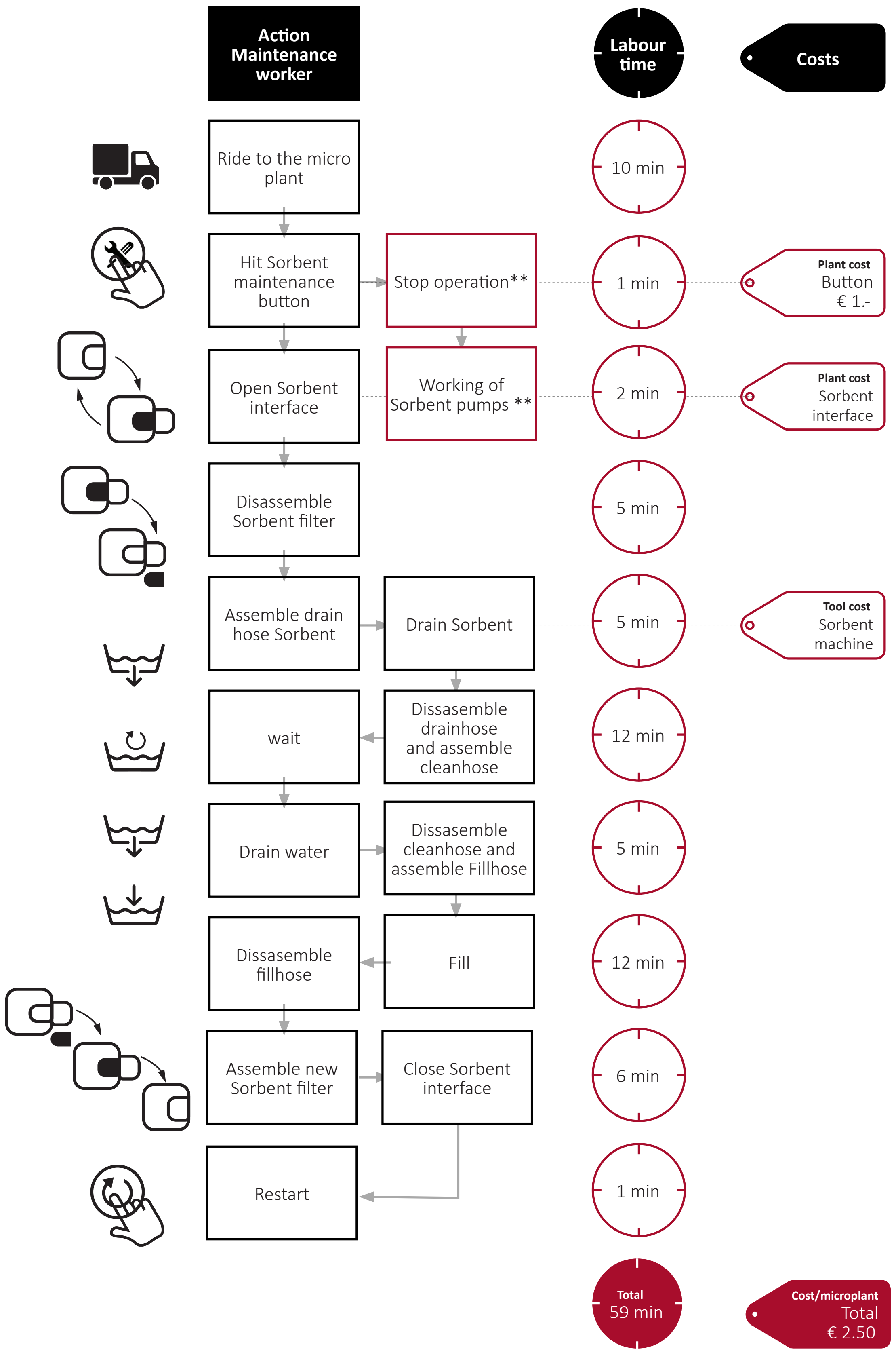

Figure 4.4 Scenario 1. timeline






*Only during maintenance moment 3.
**Action of the micro plant
***Time required without KOH 42 min

Figure 4.5 Scenario 1. maintenance moment 1, 3 and 5




*Only during maintenance moment 3.
**Action of the micro plant

Figure 4.6 Scenario 1. maintenance moment 2 and 4.



## 4.3 Maintenance scenario 2.

Scenario 2. is based on maintenance inside a garage. Assumed is that the maintenance is done with a production line. The micro plant is first swapped, with a hot-swap, and brought to the garage. All the maintenance is done inside the garage. Inside the garage, there is a production line. The maintenance is done partly automated. Assumed is that maintenance workers need to assemble and disassemble robots. The robots will automatically do the work of draining, cleaning, and filling. During this time, maintenance employees do not have to wait but can work on other micro plants. The assembly and disassembly of robots will require less time than in the field because it is a repetitive action on a production line. Maintenance always requires swapping the micro plant. Swapping the micro plant is time-intensive.

**Maintenance timeline**: Figure 4.7 illustrates the maintenance moments that take place during the 20 years lifetime of the micro plant. There are three maintenance moments. The most significant difference with concept 1 is the change in Sorbent maintenance, from every seven to every five years, so it is in sync with other maintenance tasks. The other difference is the swapping that is required during every maintenance time.
It is assumed that one maintenance moment requires a year to complete. This means that in between the maintenance moments, there is a four-year gap. This gap is too big to fill with other activities. Therefore the maintenance workers need to work temporarily.

**Maintenance scenario:** Figure 4.8 illustrates the swapping of the micro plant. Figure 4.9 illustrates the maintenance of the micro plant. Times are estimations. Prices in euro per micro plant.

**Maintenance costs**: Micro plant costs and tool costs for robots are estimated in the same way as scenario one.

Tool costs: The production line costs are based on the price of conveyor belts (source). The vehicle price is based on the price of a forklift vehicle. The micro plants needed for the swapping are estimated at the need for 40 micro plants with a cost price of 250 euro.

For the design of the micro plant, this means that the maintenance employees need to be able to access the maintenance parts to assemble and disassemble robots. It should also be easy for the maintenance employees to disassemble and assemble the complete micro plant.

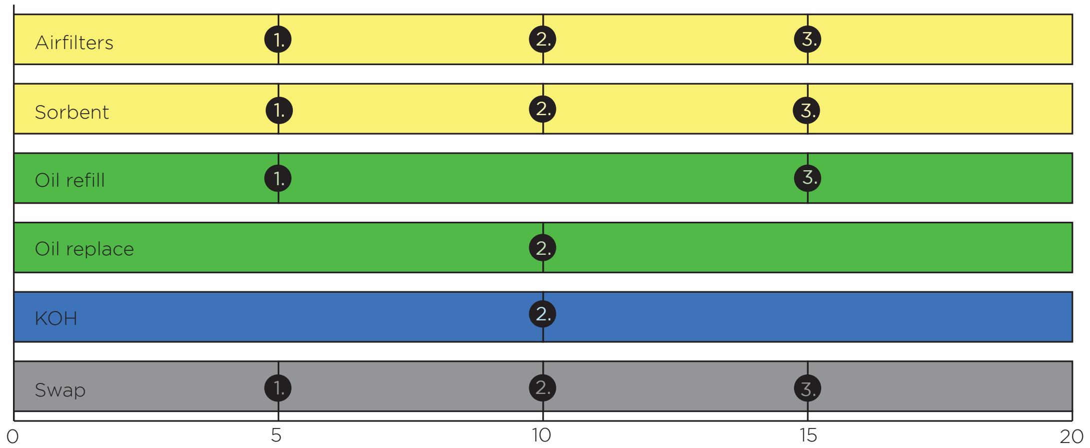



Figure 4.7 Scenario 2. timeline

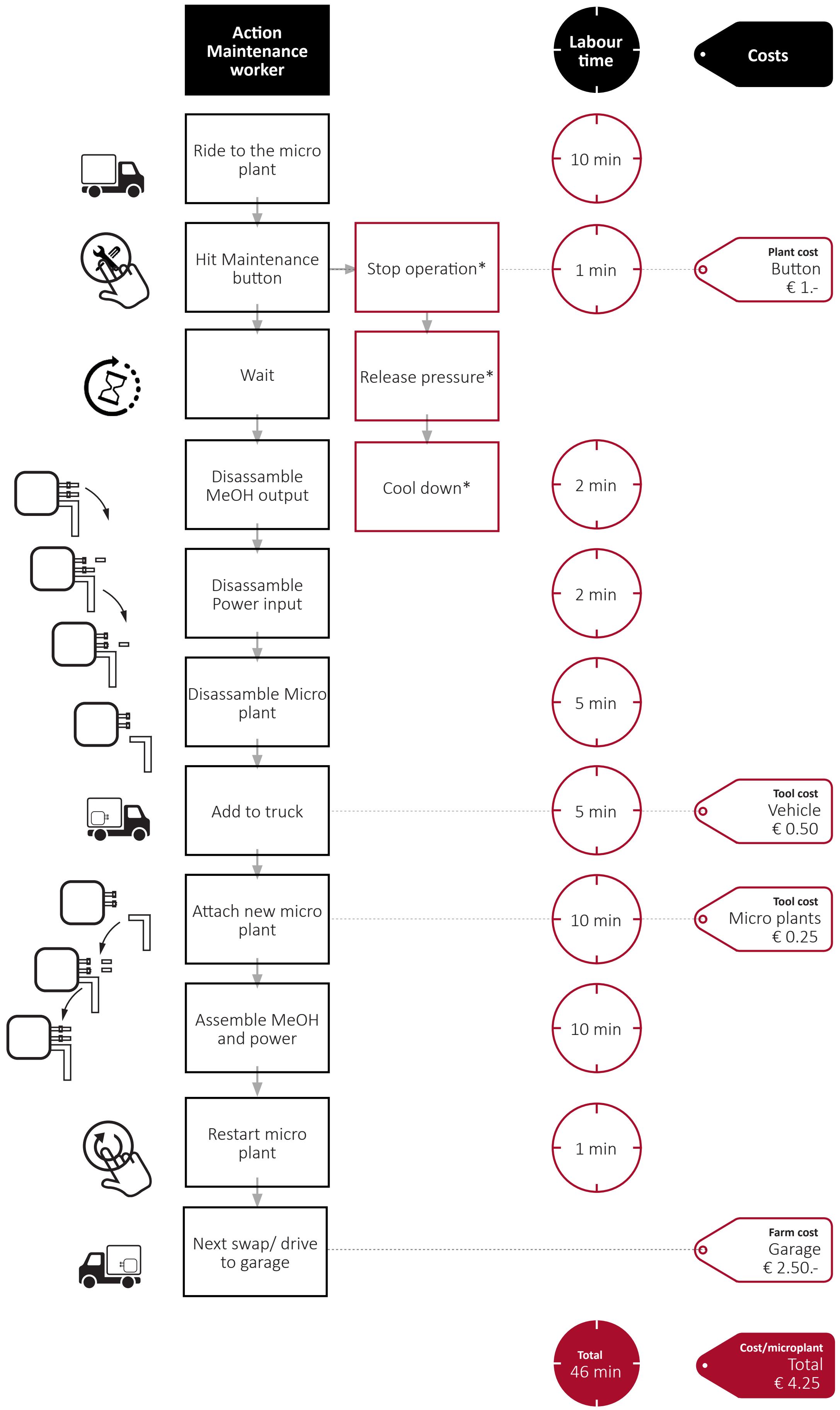



Figure 4.8 scenario 2. Swap

*Action of the micro plant



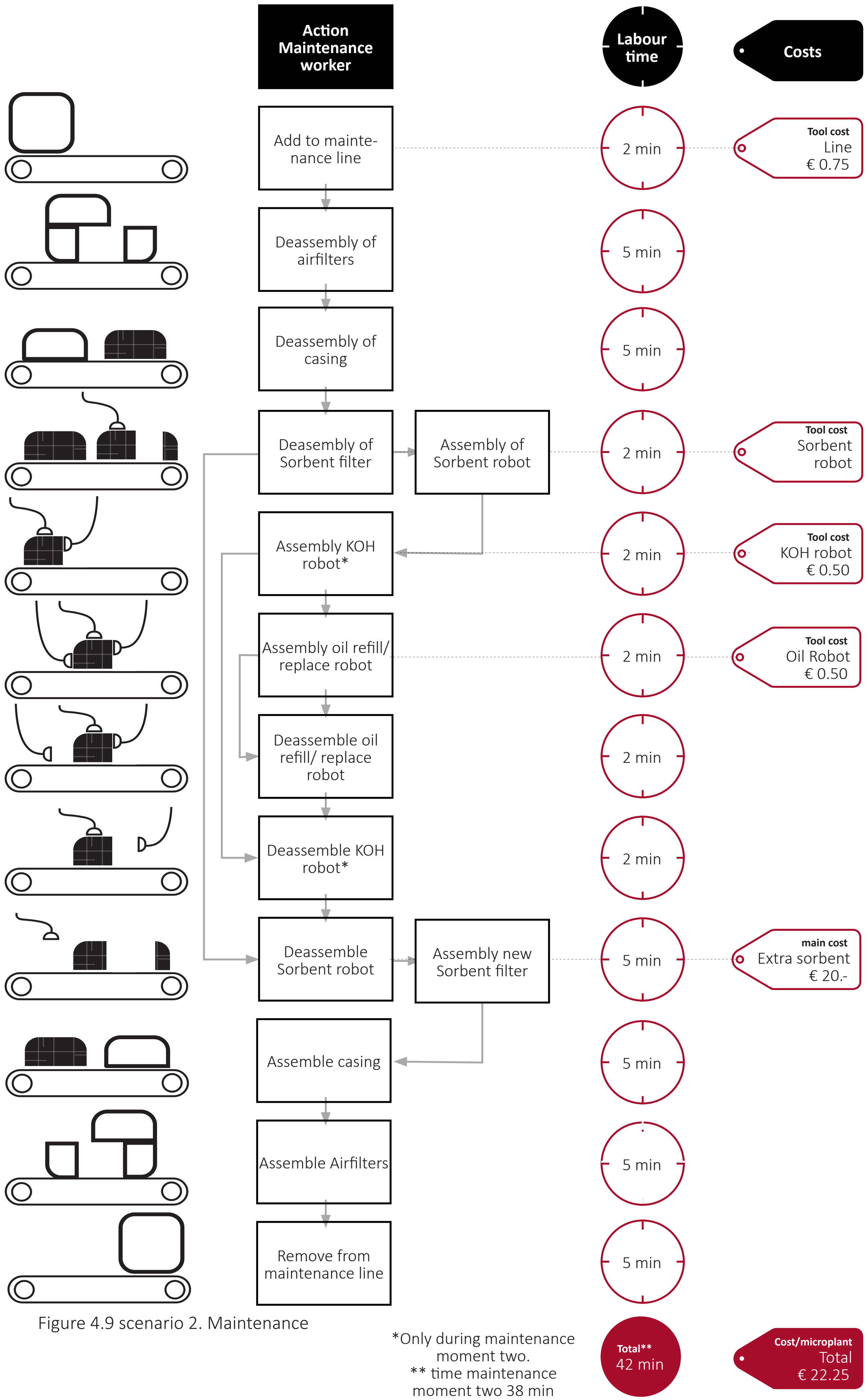



Figure 4.9 scenario 2. Maintenance

*Only during maintenance moment two.
** time maintenance moment two 38 min

# 4.4 Comparison

The times and costs per maintenance scenario are calculated and compared. The cost is 30 euro / micro plant for maintenance scenario 1. and 48 euro for maintenance scenario 2. This is not the total maintenance cost per micro plant but the costs that are different per concept. an illustration of the cost differences can be seen in figure 5.14

The cost calculation is based on the assumptions explained in §4.2 and §4.3.

**Labor costs**: calculated with an assumed hourly rate of 10 euro/ hour times the number of hours spent on the maintenance of one micro plant.
Result: There is no significant difference in the number of hours spent maintaining a micro plant, although the activities and way of working are quite different. This difference is not significant because in maintenance scenario 1. the maintenance takes more time. However, in maintenance scenario 2. the swapping of the micro plant also requires time that is spent in maintenance scenario 2. However, this result is quite uncertain and mainly based on assumptions. Advised is to do more research about the difference in labor costs later in the project.

**Tool costs:** The costs of expensive equipment like robots.
Result: scenario 2. is twice the expense of scenario 1. This makes sense because scenario 2. is more focused on automatization, and this requires money. However, the tool costs are still quite low in comparison to other costs. This is because the costs of one robot can be spread over a large number (400.000) of micro plants. This means saving one euro on a micro plant, is spending less than 400.000 euro on tool costs.

**Farm costs:** Extra costs that are needed on the farm to fulfill the chosen maintenance strategy. This is a garage with the assumed costs of 100,000 for scenario 2. scenario 1. does not make extra costs in this category.
Result: Only scenario 2 has additional farm costs. Because these costs can be spread over 400,000 micro plants, there is no big difference between the two scenarios.

**Maintenance costs:** extra costs spent on replaceable hardware parts or liquids in the micro plant. The only difference between the concepts is that for scenario 2. there is an extra replacement for Sorbent.
Result: since 2L of Sorbent costs 20 euro, this makes a big difference in the cost difference between the concepts. Because the Sorbent is such a high cost, it is advised to look into refurbishing Sorbent or only replacing the Sorbent once in the lifetime of the micro plant.

**Micro plant costs:** micro plant costs are the extra hardware costs involved in the cost price of the micro plant itself. The extra costs include buttons, extra caps, and seals.
Results: scenario 1. is more expensive than scenario 2. This is based on the assumption that there will be a casing with a maintenance interface. If the micro plant would not have a casing, these costs will be different. Figure 5.13 illustrates what interface is required for each scenario. The most significant differences are how to access the Sorbent, KOH, and oil points. It also shows that the benefit of concept 2 for the simplicity of the embodiment design is not too big.



**Loss of MeOH:** The amount of time a micro plant does not operate and no valuable MeOH is produced. In this model, the loss of these MeOH is calculated as costs.
Results: In scenario 1. there is a more significant loss of MeOH than in scenario 2. This is because the micro plant has five maintenance rounds instead of 3. Furthermore, scenario 1. does not involve a hot-swap. Nevertheless, the cost difference is almost neglectable.

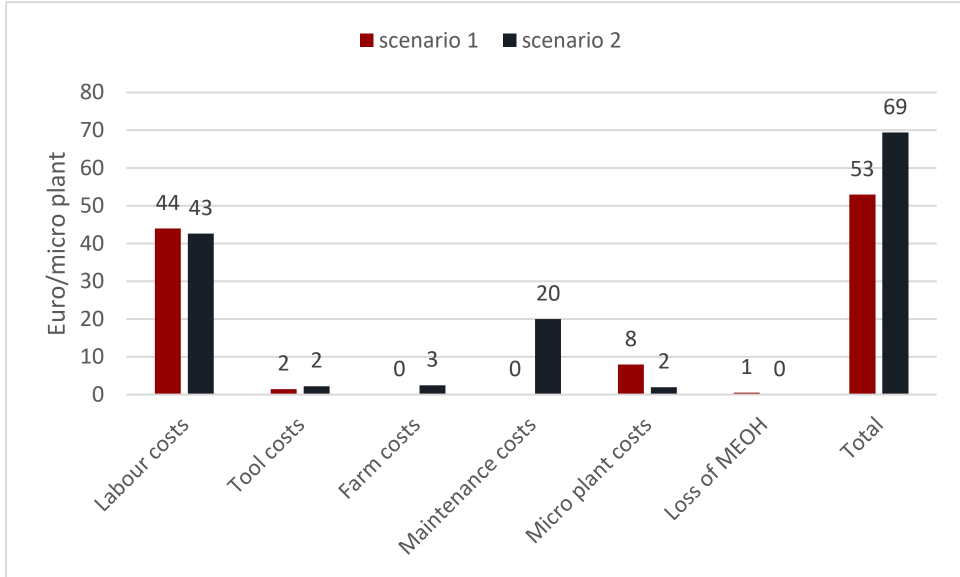



Figure 4.10 Cost difference scenario 1 and 2

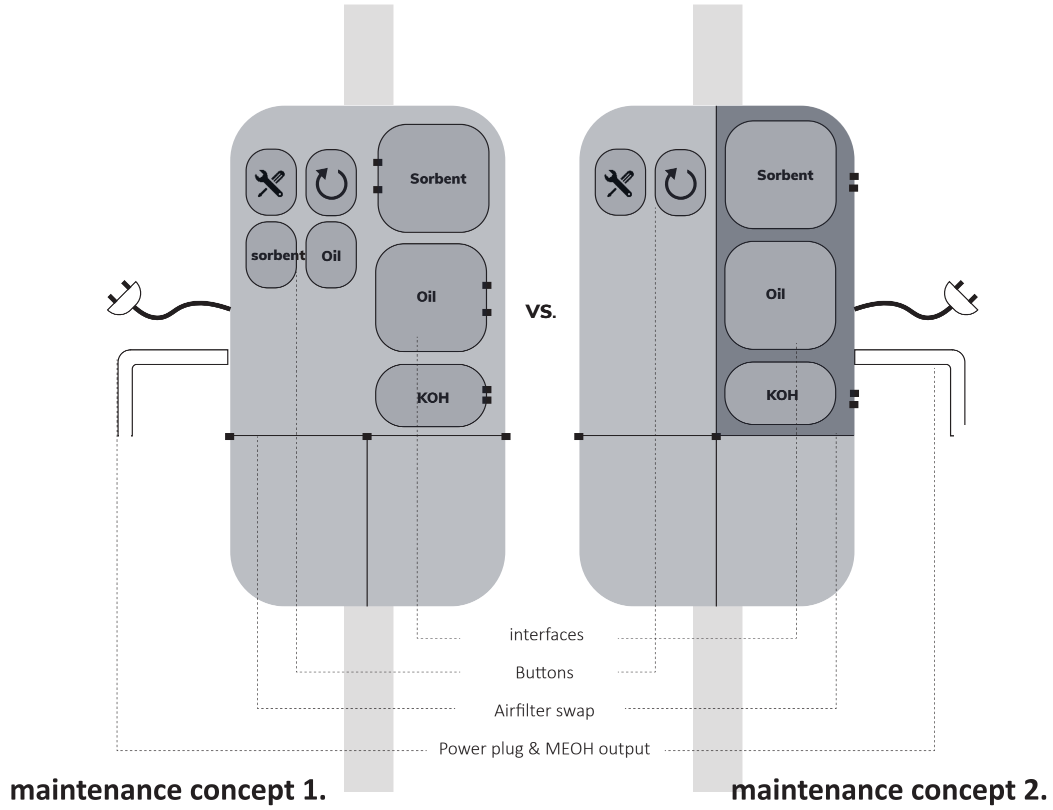



Figure 4.11 Differences in embodiment design concept 1 and concept 2

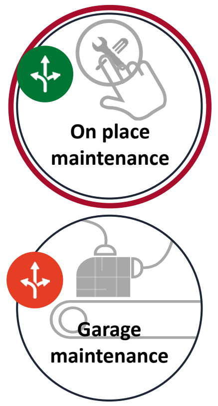
| Scenario 1. | Scenario 2. |
|---|---|
| **Pro's** | |
| Maintenance moments are flexible and can be done more or less frequently. | Climate and dust control are possible inside a garage. |
| Maintenance tasks that are combined can easily be split or vice versa. | It is easy to add extra maintenance and controlling procedures since the whole casing will be opened. |
| No need for swapping the micro plant. | Robots can stay in one place, therefore they can be bigger and more advanced to create a higher level of automation. |
| Cheaper option. | More ergonomic work circumstances. |
| Possible to see the micro plant operating in the field and gain knowledge about it. | A line can decrease labour time. |
| **Con's** | |
| Extreme weather conditions, like heat and dust, can create an unpleasant work environment and risks for the micro plant when opening the micro plant. | Need for swapping the micro plant. |
| More time-consuming. Waiting time of for example drainage is part of the labour time. | Scheduled maintenance moments are less flexible to shift. |
| Requires extra casing costs for the micro plant. | If one single task needs to be done swapping is needed. |
| Tools and robots are used outside and need to be transported to the micro plant. | More expensive option. |
| | Requires a garage. |

Table 4.12 differences scenario 1. and scenario 2.

Table 5.1 explicates the differences between scenario 1 and 2. It illustrates that both scenarios have their pros and cons and that both of them could be beneficial depending on the requirements of the maintenance.

## 4.5 Conclusion

Scenario 1 is chosen for the embodiment design of the micro plant.




This scenario was cheaper in the analysis. However, it is also not realistic to assume that for the first 100.000 micro plants, the predetermined maintenance schedule will be followed as planned. After operating the first farm, data needs to be collected to evaluate the maintenance strategy. Scenario 1 allows small changes to the maintenance schedule without changing the design of the micro plant.

However, the analysis also illustrates that a significant maintenance cost is the labor costs. For the design of the micro plant, this means that designing the maintenance in a way that can be done fast can decrease OpEx. Nevertheless, this analysis can not perfectly illustrate the highest maintenance costs because it only shows the maintenance costs that create a difference between the two scenarios. This comparison shows that the cost difference is still based on a large number of assumptions and that the differences between the scenarios are too small for harsh conclusions.

For the design of the micro plant, this means:

- The focus is on easy and fast maintenance at the place of the micro plant.



- Maintenance robots are used to decrease labor time.

It needs to be possible to check if the micro plant is operating or needs repair. It is not necessary to use a visual signal on the outside of the micro plant. A maintenance worker could also use an infrared to check if there is still heat generated by the micro plant. If there is no heat generated anymore, the micro plant needs repair. Controlling the working of the micro plant could also be done in other ways, like using a drone that creates infrared camera visuals.
The requirements derived from the maintenance study are illustrated in figure 4.x, this illustration answers the research question: *How will the optimal maintenance journey affect the design of the micro plant?*

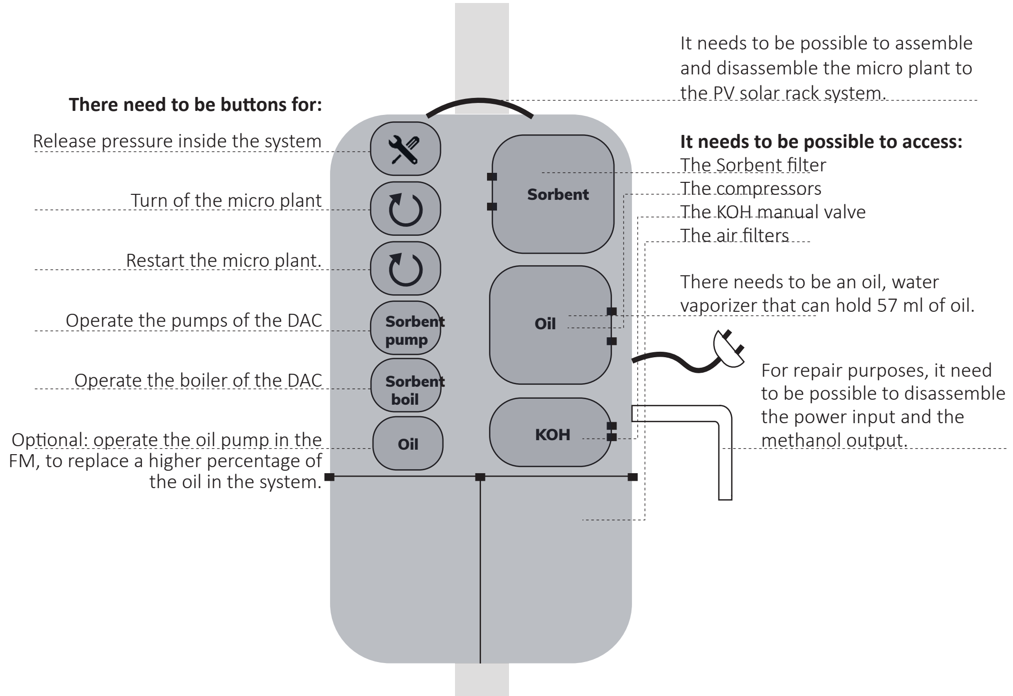



Figure 4.11 Requirements derived from the maintenance study

## Key takeaways

- **Type of maintenance: predetermined preventive scheduled maintenance.**
- **There is a 2 to 5 years time interval between maintenance moments, which means that a fulltime maintenance team is discussable.**
- **Two concepts; on place maintenance and robot maintenance in a garage. Main design driver: flexibility, maintenance in a garage offer little to no flexibility to change the maintenance schedule. For the first farms, it needs to be possible to shift in the maintenance schedule.**
- **Robots that can do maintenance in place can reduce 'expensive' labor costs.**
- **The comparison between the two scenarios is based on numerous assumptions. Therefore the difference between the scenarios is not significant enough to draw hard conclusions. The primary insight is that the difference is not that significant and that after pilot testing, more research is needed for a reliable maintenance consult.**
- **The final embodiment design requires buttons and access to maintenance parts.**

# 5. Architecture design

**Objective**: To integrate all parts optimally.

**Research question:** How do heat and cooling efficiency influence the architecture design ?

## 5.1 Introduction

Table 5.1 illustrates different solutions for ten problems that arise when developing an embodiment de-sign for the ZEF micro plant. The first eight problems are about how to distribute different parts within the micro plant to create an architectural design. For each part category different ideas are proposed. For each problem one or multiple ideas are chosen to be implemented in a concept. Two concepts are generated.

Concept 1 & Concept 2.

Occasionally similar or identical ideas were chosen to be implemented in both con-cepts. The rest of the chapter will explain and argue the two concepts. The chapter ends with an evalua¬tion and a conclusion that will be used for the next iteration.

The concepts are detailed with choices about the type of insulation, the type of casing, and the applied maintenance scenario. It is relevant to see how these choices influ-ence the architecture design of the micro plant. Appendix E explains the choices in more detail with more illustration.

*Note: some parts have been updated after the creation of concept 1 & 2 and concept 3. Therefore the parts illustrated in the figures might be slightly different from those described in appendix A*

## 5.2 Concept 1.

Figure 5.2 and 5.3 illustrate a 3D rendering of the architecture design. This image is to illustrate where the different parts are positioned. The colors illustrate to which sub-system the parts belong. Figure 5.2 and 5.3 are simplified versions of the architecture design. The parts are simplified in shape, and the connecting pipes, insulation sensors, and wires are not illustrated. All individual parts requirements, like orientation and cooling, are met in the architecture design. The figures indicate how the ideas from the morphological chart are implemented in the design. An argumentation is given for the choice of ideas and their implementation.

Figure 5.1 illustrates a schematic top view of concept 1.

- The absorption column is in the middle and functions as a base. This is because the absorption collum is one of the largest parts in size.
- The parts of the DAC that are not the absorption column are on the same side as



the AEC, because they both require insulation.
- The MS is a long part; therefore, it is placed on the front, on the long edge of the design. In this design it could also have been placed at the back.
- The air filters are placed at the bottom of the design; this allows the wind to blow off dust.
- Air needs to be conducted from the top of the absorption column to the air filter. The air duct is not illustrated in the figure. The air duct could be placed next to the FM subsystem.

**Insulation material:** figure 5.4 illustrates the place of the insulation. It is chosen to use solid premanufactured insulation. The influence on the architecture design is about the space that is required for the insulation.

**Casing:** The architecture design influences the volume of the casing. The casing does not have a considerable influence on the architecture design (figure 5.5).

**Maintenance:** The maintenance scenario influences the position of maintenance parts, as described above.

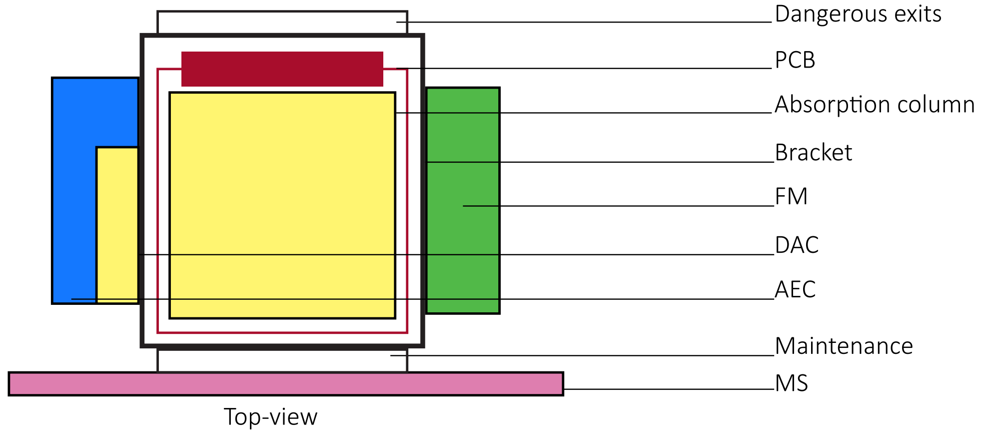



Figure 5.1 Schematic overview concept 1.

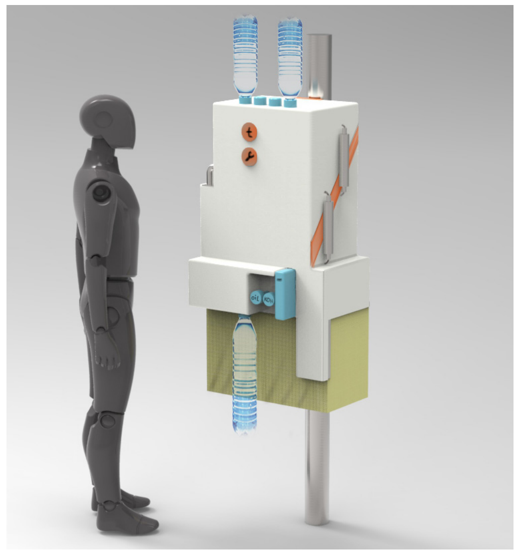


Figure 5.5 Maintenance and casing

**1f. Wires distributed behind a bracket:** Having the PCB in between the absorption column and the bracket makes it easy to distribute the cables to the different parts. The cables will come from behind the bracket.

**1b. Maintenance on one side, outside the casing:** Having the subsystems together makes it easier to distribute the maintenance parts (parts that require maintenance). Having al the maintenance parts on one side of the plant makes it easier to create an ergonomic maintenance interface. It also makes it easier to have dangerous outputs, like an O2 purge on a side that does not directly require human interaction.

**1a. Subsystems kept together:** It is chosen to keep subsystems together. Subsystems together create a better overview, and the distances between different parts can be kept short, resulting in shorter piping constructions.

**1g. Hang parts on a bracket:** In concept 1. the parts are hanged on a bracket (sheet metal frame), the bracket is placed around the absorption column.

Figure 5.2 Architecture design front

**1b. Dangerous exits on the other side than the side of the maintenance**

**1e. PCB attached to the absorption column. & 1e. PCB behind a bracket:** The PCB is attached to the absorption column because it is in the middle of the architecture design. When the PCB is positioned at a centralized space in the design, the wires can easily access all the sensors. It is also good to have the PCB at a place where it can release heat into the environment.

**1d. Cooling parts outside the casing & 1d. Cooling parts on the other side of the maintenance side:** In concept 1 the cooling parts are outside the casing; this is to allow outside air to cool the parts. Cooling parts can become hotter than 60 degrees Celsius. For a safe maintenance interface where the maintenance employee is not in direct danger of hot parts, the cooling parts are not positioned on the same side as the maintenance interface.

**1c. Insulation parts together:** Insulation parts are kept together as much as possible; this is to reduce insulation material and heat leaks. In this way hot parts can share their heat with other parts that need to be hot.

Figure 5.3 Architecture design back



# 5.3 Concept 2

*Note: For this design maintenance scenario 2 was used.*

The figures are a simplification of the architecture design. Piping connections, insulation, and wires are not illustrated. The air filters are underneath the micro plant for the same reason as in architecture design 1. Figure 5.7 and 5.8 illustrates the architecture design. The colors indicate to which subsystem the parts belong. The orange part is the air duct.

Figure 5.6 illustrates a schematic overview of concept 2. It illustrates where the different subsystems are placed.

- The absorption collum is placed on the right, and all other small parts are placed on the left. Positioning all the small parts of different subsystems in the same area can save space, and it allows stacking parts on top of each other.
- Having all the parts on one side of the absorption column also allows the cooling parts to be inside the air duct.
- The MS is placed in the back over the long edge of the design. The MS is placed in the back because there it is closer to other parts that require insulation and to the parts that it needs to be connected with piping. The MS is also placed at the back because of its large size.

**Insulation material**: figure 5.9 illustrates the place of the insulation. Loose insulation flakes are chosen. This will influence the architecture design based on how these flakes are confined. For example, an extra to separate insulation parts from other parts might influence the architecture design.

**Casing:** the casing does not have a direct influence on the architecture design.

**Maintenance:** The parts are distributed based on the choice of maintenance scenario. For this architecture design, maintenance scenario 2 used (figure 5.10).

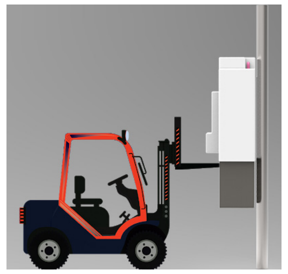


Figure 5.10 Casing and maintenance

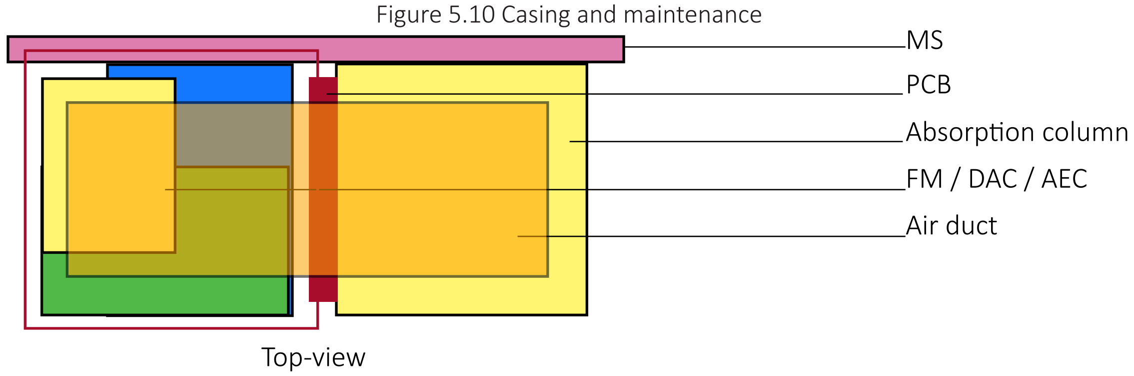



Figure 5.6 Schematic overview concept 2.

**1a. Mixture of all subsystems:** The subsystems are mixed because there is no need to have a strict order when maintenance parts do not have to be on the same side.

**1e. PCB attached to the absorption column:** The PCB is attached to the absorption column, next to the air duct. If necessary, the PCB can be placed inside the air duct.

**1f. Wires distributed with cable tray**: The wires will be distributed using a cable tray. This method is also proven to be effective in the car industry.

**1g. Stack inside the casing:** Concept 2 does not use a bracket to attach parts; instead, it stacks parts on top of other parts. The piping construction will also create stiffness. Inside the casing, ribs can be added to fit parts.

Figure 5.7 Architecture design front

**1d. Cooling parts inside the air- duct:** to close the casing, the coolers are places in the air duct. The air duct conducts the air that comes out of the absorption column down to the air filter. The air duct conducts 600^m2 air an hour. Because of this airflow, the cooling parts are cooled better than using outside air. It also protects the coolers from fouling (the accumulation of unwanted materials on solid surfaces). The coolers are not visalbe because they are inside the air duct.

**1c. Insulation parts together:** The solution for parts that require insulation is the same as in concept 1. The insulation parts are kept together to create an optimal heat scenario.

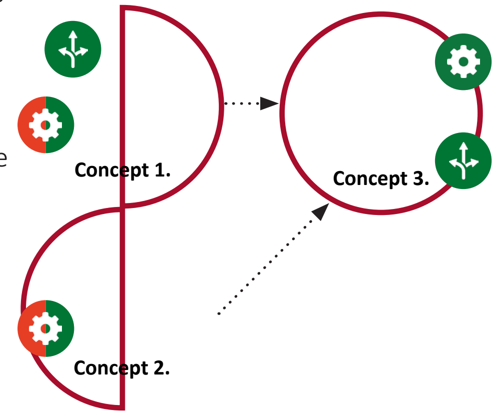
**1b. Maintenance not centralized inside the casing:** Maintenance parts are all inside the casing. Because maintenance will happen in a garage with a con-trolled environment, it is possible to open the whole micro plant.

Figure 5.8 Architecture design back



## 5.4 Evaluation

**Architecture design:** The architecture design of concept 1. and concept 2. is different. Table 5.x compares the two concepts and generates guidelines for the next iteration.




It is not sure if an utterly closed casing is an advantage. Because stainless steel parts are connected with stainless steel piping, both are not sensitive to adverse weather conditions, dust, or animals. Only wires and sensors might be sensible to this, but they can be protected with separate solutions for these individual parts.

It is unclear how the placing of the PCB and the distribution of wires affects the archi-tecture design and the cost price of the micro plant. However, it is assumed that the choice of the wire distribution and PCB orientation only has a minor effect on the final cost price. Therefor a good comparison between the two concepts is not possible.

| Advantages of concept 1 | Advantages of concept 2 | Next iteration: |
|---|---|---|
| Having a structured overview over the different subcomponents. | | keep the subsystems together, like in concept one. This will create over-view and a more flexible and future proof design. However, these |
| Having all the maintenance parts on the same side allows for an easy-to-operating interface. | Having the coolers in the air duct. | subsystems should be on one side of the absorption column, to allow all the cooling parts to be positioned inside the air duct. |
| Subsystems might still change in the future, and with this design, parts can get bigger or smaller without changing the basic principles of the architecture design. | Not needing a bracket, resulting in fewer parts and, most likely, lower costs. | In the next iteration a bracket will not be used. |
| Attaching parts to a bracket can be an advantage because of the overview and stiffness. | | |

Table 5.x Architecture design comparison concept 1 & 2

**Insulation:** Concept 1 used the principle of solid insulation and concept 2, the principle of insulation flakes.
Both architecture designs allow placing the insulation parts in the same area. Theoretical, this has an advantage over spreading parts that need insulation because parts keep each other hot.
For the next iteration, it is best to place the parts that require insulation close together.

**Casing:** Both concepts only illustrate the volume of the casing. There is no significant difference between the volumes of the casings. It is assumed that the casing of concept 1 is more expensive because of the maintenance interface and the coolers outside the system.

Concept 2 might require ribs on the inside of the casing to support and structure the parts. These ribs might require more costs.
The initial choice of an injection molded casing for both concepts is questionable because injection molding requires substantial investment costs, and the shape of both casings can be simple enough to consider other production methods.
For the next iteration, the casing needs to be redefined.

**Maintenance:** From the two concepts, it can be concluded that the maintenance scenario affects the choice of architecture design and the casing. The insulation is not significantly affected by a different maintenance scenario.

## 5.5 Concept 3

**Architecture design:** Concept 3 is an iteration of concept 1 and 2, and an embodiment of the results from the maintenance research. Concept 3 does not yet have a detailed embodiment of the insulation and the casing. Therefore the focus of concept 3 is an architectural design that is used as a starting point for the design of the casing and the insulation.

Figure 5.11 illustrates a schematic top view of concept 3.

- The air filters are underneath, and the absorption column is on the right. T
- he other  DAC parts are placed on the left, together with the AEC parts. They are together because both AEC parts and DAC parts need insulation.
- The MS part that needs the most insulation is placed next to other parts that require insulation.
- The MS is on the back because it would block access to parts that require maintenance on the front. On the back, it is closely connected to the purge and pressure relief parts. This results in shorter piping connections.

Figure 6.2 and 6.3 illustrate architectural design in a simplified way. The colors indicate the different subsystems according to the color scheme of figure x.1. The purple part is the PCB. These figures do not illustrate the air duct, insulation, sensors, and wiring. The figures illustrate that the air filters are a bit apart in the design. It is necessary to have space between the air filters and a separation wall between the air filters to

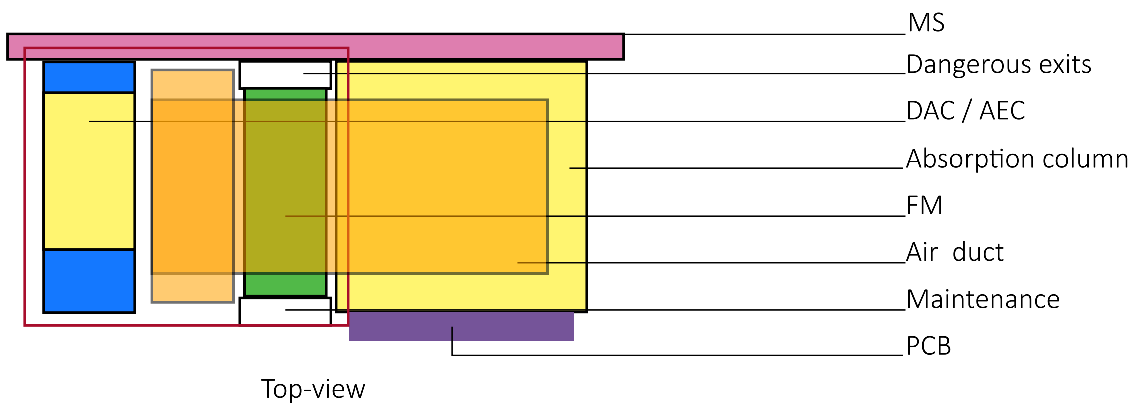



Figure 5.11 Schematic overview concept 3.



In between the FM and the AEC and DAC, insulation is an air duct. This air duct conducts the air from the top of the absorption column to the air filter out. This air duct is in between these subsystems because inside the air duct, the coolers are placed. This configuration allows the DAC subsystem and the FM subsystem to be close to the air duct.

The absorption column is placed directly above the air filter that sucks in the air.

Next to the absorption column is the FM subsystem. The FM subsystem has parts that require maintenance, the maintenance parts, are placed in front of the FM.

Figure 5.14 Air duct

n the back of the FM, where maintenance does not occur, are the purge and the pressure relief valves.

Pressure relief and purge parts need to be on the opposite side of the maintenance, to prevent harming maintenance employees. The back of the FM is also the right place for the pressure relief parts and the purge parts because there is room, and it is a centralized place in the design.

Figure 5.13 Architecture design back

prevent air circulation within the micro plant.
Figure 6.4 illustrates the architecture design with the air duct. The air duct is grey and positioned according to figure x.1 between the FM and the AEC and DAC.

**Insulation:** Figure 6.5 illustrates where insulation should be placed. The exact thickness and shape of the insulation can still change. Having the insulation in this part of the design also allows the design to adjust to new insights. If the insulation becomes smaller or bigger, this is possible without changing the basic argumentation behind the architecture design.

**Casing:** Figure 6.6 illustrates the volume of the casing in the context of 3 PV solar panels and a solar pole. As can be seen, the air filters hang underneath and are not covered by the casing; this is to allow the wind to blow off the dust. The orange part on the casing is the cover to access the maintenance parts.

**Maintenance:** Figure x.7 illustrates how the maintenance interface looks like when removing the maintenance cover. Next to the maintenance inter-face are some maintenance buttons.

Figure 5.16 Casing

Figure 5.17 Maintenance



## 5.6 Conclusion

**Architecture design:** The objective was: *'To integrate all parts optimally.'* The basic architecture design, as illustrated in figure 6.1, is an excellent base for further itera-tions. After evaluating the different subsystems, only a few minor changes in piping construction need to be changed, for instance, making a smaller PCB and placing these inside the air duct. The architectural design is flexible for changes withing the subsys-tems. A different architectural design will give problems with getting al the parts in the cooler, having insulation parts together, and having maintenance parts together. The architectural design is a solid base to add more details about sensors and wiring.

**Insulation:** A research question was: *How do heat and cooling efficiency influence the architecture design?* The solution is: parts that require insulation are close together. They are positioned at a place where a bit more or less insulation will not majorly affect the architectural design. The other solution is coolers in the air duct.

**Casing:** The shape and volume of the casing allow for multiple opportunities. More research is needed to define the material, shape, and production method of the casing.

**Maintenance:** It is good that all the parts that require maintenance, except for the air filters, are close together. This generates the opportunity for an ergonomic main-tenance interface. This interface can be safe because hot elements are within the air duct, and the purge and pressure reliefs are on the other side of the casing. However, more details are needed on how the maintenance should take place precisely and on how this should be embodied.

**Conclusion:** The architectural design will except for some minor changes that stay as concept 3. Insulation and casing will be researched for the next iteration. Maintenance will be more detailed.

### Key takeaways

- **The requirements of the parts, together with their place in the system diagram, already give the parts a position in the architecture design.**
- **The MS, absorption column (part 2), the stack (part 47), and the air filters (part 1 &4) determine the volume size of the micro plant. Changing the dimensions of these parts almost immediately results in different dimensions of the micro plant. Changing other parts will have little to no influence on architecture design.**
- **Key drivers for the architecture design where:**
  - **Maintenance parts accesible**
  - **Coolers in the air duct**
  - **Insulation parts close together.**
  - **Subsystems close together**
  - **Exits opposite to maintenance parts.**

# 6. Insulation

**Research question:** How do heat and cooling efficiency influence insulation?

## 6.1 Introduction

Figure 6.1 gives an overview of the different parts that require insulation.
Heat is generated by different means. An option in the future can be that heat used for the DAC is generated with a solar heater. For now, it is assumed that the micro plant generates heat with solar energy.

Good insulation requires less energy to maintain the desired temperature.

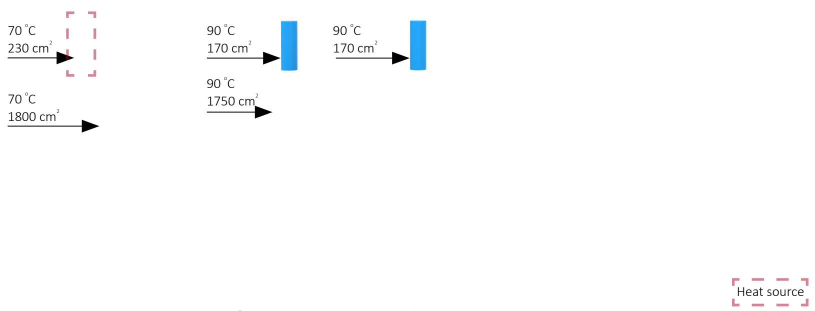



Figure 6.1 Casing configurations part design

**The main objective of the insulation is: To minimize energy leakage and increase energy efficiency.**

Some parts exceed temperatures of 200 degrees, while other parts remain around temperatures of 90 degrees. Different temperatures require different insulation materials and thicknesses. One option is to select different insulation materials. The other option is to adjust the thickness of the insulation based on the ideal temperature. Thermal insulation stops one or more of the three modes of heat transfer: Conduction, convection, and radiation. Thermal insulation materials reduce radiation and or conduction of heat.

## 6.2 Material selection for thermal insulation

For the insulation material, the CapEx cost of the insulation must balance the OpEx gain. Factors that contribute to this are:
1. **Insulation efficiency**-> Low Thermal conductivity, the density of the material, specific heat capacity, the thickness of the isolation material, and the absence of heat leaks.
2. **Price** -> price of the material
3. **Lifetime**-> is the material after 20 years just as efficient as in the beginning?

Furthermore, the material has to fulfill the following requirements:
4. Can withstand **temperatures** of minus 18 and maximum 300 degrees Celsius. This temperature application range is specific for the MS; if a different material is used for the AEC and the DAC, the temperature range is different.
5. The insulation material has a class A or B **resistance to fire**.
6. The insulation fits the **mass production** of 100,000 pieces.



The materials are selected from materials proposed in the literature (Asdrubali, D'Alessandro, & Schiavoni, 2015; Papadopoulos 2005; Schiavoni, Bianchi, & Asdrubali, 2016) and CES EduPack software (2019) . The selection of the CES materials and the suitable materials in the paper can be found in appendix F1. The main conclusion of the analysis from the papers and the database is that numerous materials classify as insulation material, but only a few materials can handle high temperatures. Two materials scored significantly better on their ratio between thermal conductivity and cost: Glasswool and stone wool.


An interview with the company InsulationSolutions confirmed that glass wool and stone wool could be used for insulation. The other options they proposed and the reasoning about why these options will not be used can be found in appendix F2. Therefore, the choice is to use glass or stone wool. For the insulation of piping, it is common to use stone wool. Glass wool can lose its density and, therefore, part of its thermal properties.

**Conclusion:** Stone wool will be used as the insulation material of the micro plant.

## 6.3 Production of stone wool insulation

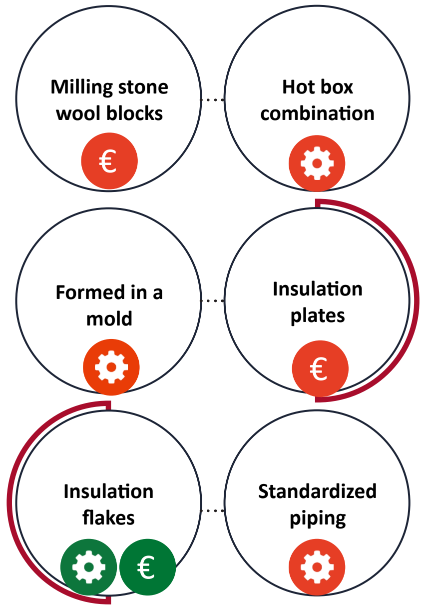
There are several different ways to apply the stone wool material to the micro plant. The selection criteria for the material selection are also relevant for the selection of the manufacturing method. Other deciding selection criteria are the manufacturing method's possibility to prevent heat leaks and a tight-fit to the parts. There are different manufacturing methods:

- Insulation plates
- Standardized piping
- Milling of stone wool blocks
- Insulation flakes
- Stonewool formed in a mold
- A hot box in combination with different options.

Appendix F3 describes the different manufacturing methods.

**Conclusion:** A rule of thumb for the cost-price of the insulation is that the material

itself is only 1/6 of the price. The rest of the cost price is the labor needed for the assembly of the insulation. Therefore standardized piping insulation will not be chosen.
The best solution is easy to assemble. Fits the micro plant perfectly, does not require expensive secondary processes or labor and does not require a casing.
Therefor two solutions will be combined. Standard stone wool plates will be placed around the insulation parts. Now the parts do not have a tight assembly. Therefore the room in between the part and the plates will be filled with insulation flakes. The advantage of this is that it can be done with premanufactured materials that are available on the market and do not need secondary processes to fit the design, except for cutting it at the right size. Moreover, it is
easy and quick to assemble. In this way. All the advantages of having loose insulation flakes can be used without needing a particular casing.




## 6.4 Insulation protection

It is researched if there is another, cheaper possibility to protect the insulation material from airflow, water, and animals than a closed casing.
A brainstorm exposed the options illustrated in figure 6.2

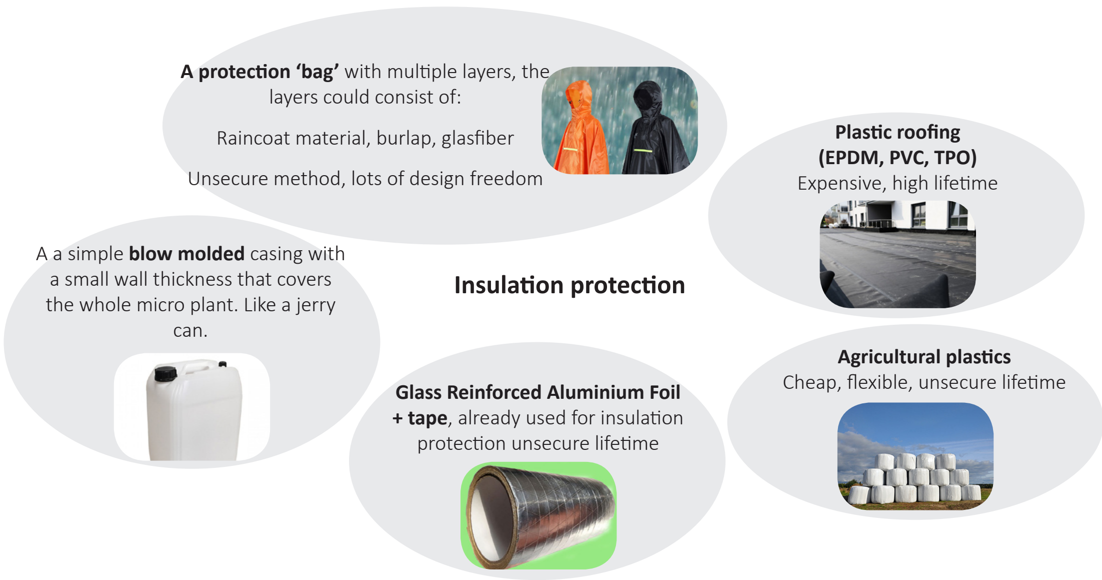



Figure 6.2 Insulation protection brainstorm



Table 6.1 evaluates the options from the brainstorm. The table evaluates the options for three different selection criteria:
1. can the solution withstand 20 years lifetime under high UV?
2. Is the solution suitable for the manufacturing and assembly of 100.000 pieces?
3. cost price; can it be assumed that the solution is significantly cheaper than a casing?
Selection criteria 1 and 2 are a go/ nogo selection criteria. The cost price should be lower than the cost-price of a casing,
Conclusion: It is possible to use agricultural plastic. Based on this analysis, the assumption can be made that this will be more economical than a casing.


| | Protection bag | Plastic roofing | Agricultural plastic | Aluminium | Blow molded |
|---|---|---|---|---|---|
| 1. | ? | ✓ | ✓ | ? | ✓ |
| 2. | ✓ | ✓ | ✓ | ✓ | ? |
| 3. | € 20,- | € 60,- | € 10,- | € 20,- | € 40,- |

Table 6.1 Insulation protection

Legenda:
? Unsecure if requirement can be met.
✓ Possible to meet the requirement.

## Key takeaways

- **Stonewool has the best thermal properties, price, and durability compared to other products.**
- **Material is significantly cheap compared to the assembly costs.**
- **There are several ways to produce and assemble stone wool; important decision drivers are the ease of assembly and the prevention of heat leaks.**
- **The chosen method is a box of stone wool plates tilled with stone wool flakes.**
- **Stone wool needs a protection layer; this layer does not have to be a casing.**
- **The protection layer can be a simple layer of plastic or aluminum.**
- **The production/ assembly of stone wool and the protection layer requires more research than done within this project; the choice was based upon several assumptions,**

# 7. Casing

**Objective:** To design a casing that can fulfil its core functions.

**Research questions:**

2. What are the core functions and limitations of the casing?
3. What are the micro plant properties and the main shape of the casing?

## 7.1 Introduction

The casing needs to protect the micro plant from the desert circumstances. It needs to endure a lifetime of 20years and have a low-cost price.
It needs to be suitable for a batch size of 100.000 pieces. It is desirable to have a design that can suit a smaller batch size for the pilot phase. This smaller batch size Is estimated to be 1000 pieces. It Is crucial to design for a batch size of 100.000 pieces because the ZEF business model is based on the advantage of mass manufacturing over building a large installation at once. Mass manufacturing methods have lower piece prices when the batch sizes are large compared to other manufacturing methods.

## 7.2 Benchmark

Modern PV solar parks have small inverters behind their solar panel to transform energy. Inverters are simple products with a PCB, a casing, and connectors to connect the inverter to the solar panel.

Figure 7.1 illustrates the inverters of different companies. It is not always visible from the image. Which material and production technologies are used to produce the invertor.

An interview with Mastervolt (appendix F2), a company that produces invertors for the marine industry, gave insight into the use of sheet metal to tor the casing because of production volumes, fast design iterations, heat transfer, and fire resistance.


Figure 7.1 Inverters of different companies.



Invertors need to meet the norms of IEC 62109. There are no IEC norms tor micro plants because micro plants do not
exist yet. However, assumed is that the micro plant needs to follow most rules that apply to inverters. Appendix G lists the rules that could be relevant to the design of the micro plant. Vital design clues from the analysis are that emergency buttons need to be red. Furthermore, Accessible parts can not exceed temperatures of 100 degrees.

## 7.3 Layout of the casing

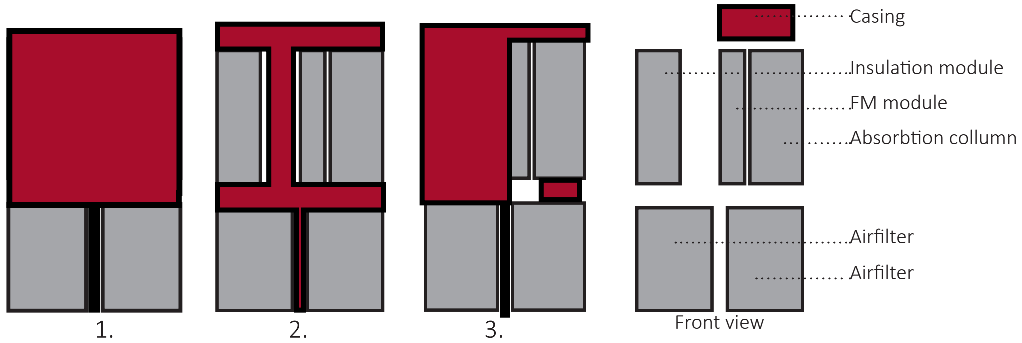



Figure 7.2 Casing layouts

The casing can be made with different layouts and production techniques. Figure 7.2 illustrates three different casing layouts. For this analysis, it is not relevant how the layout can be built on the inside, but more how it affects the design of the micro plant from the outside. There are three different types of layouts:

- Layout 1: This layout encloses the whole micro plant.
- Layout 2: This layout only creates an air duct.
- Layout 3: This layout contains an air duct and an enclosure for the insulation module.

Appendix G.2 lists the pro and cons of the three different layouts.

**Wires** (figure 7.3): In the car industry, animals gnaw through wires, this is a known problem; often done by martens, Assumed is that wires can be protected from animals using wire protection 0.10 €/m (A.libaba, 2020) and transit glands with boxes.

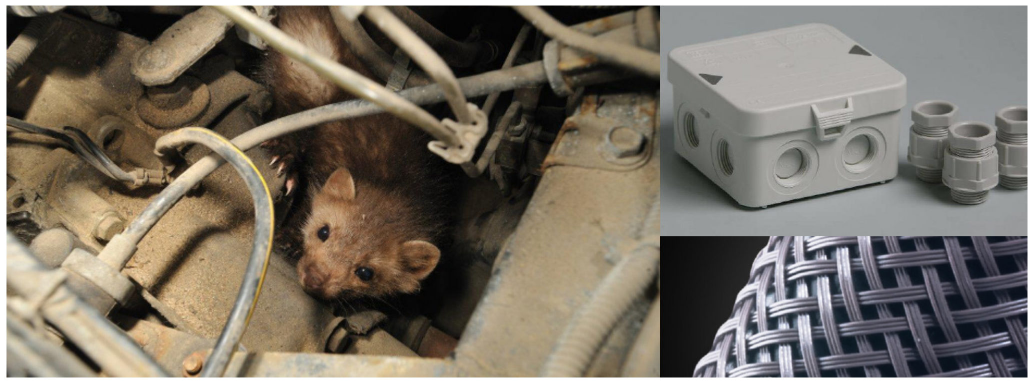
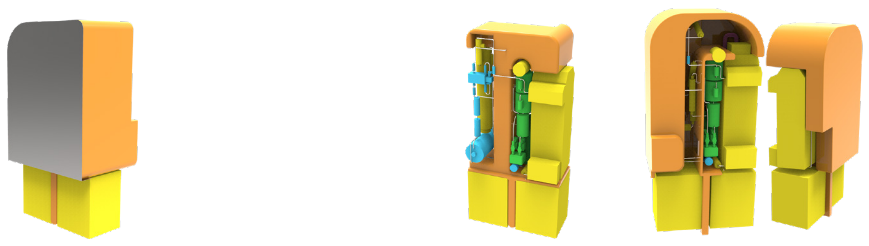


Figure 7.3 Wires protection

Evaluation: A small comparison of hollow parts made with the three different layouts, illustrates the differences in the required material. The material that is required can be an indication of the end price of the part. For these three layouts, it Is assumed that they are hollow on the inside, with 2 mm wall thickness and Polypropylene plastic. A larger wall thickness might better suit, but the design is mainly used for comparison. Figure 7 .3 illustrates the designs used for comparison.
The weight of the layouts is as follows:

- layout one: 8kg
- layout two: 4 kg
- Layout three: 6 kg

If the layouts were designed with a different production technique in mind, the results would be different. However, this comparison illustrates that only producing an air duct does benefit over producing a fully enclosed casing. The bigger and the more complicated a part will get, the more complicated and expensive it will be to manufacture it.

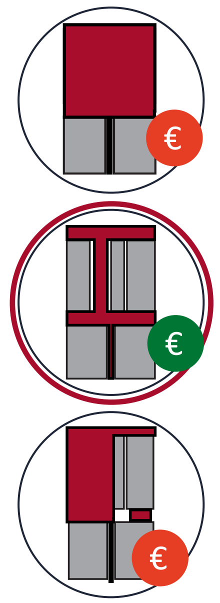


1. 2. 3.

Figure 7.3 Layout casings, part design



## 7.4 Layout conclusion




It is best to have the layout of the casing that is as simple as possible. Layout 1 is the most complex. Layout 2 or 3 can only be chosen when the following two requirements are fulfilled:

a. According to the IEC norms for inverters, touchable parts are allowed to get up to temperatures of 100-C. With the FM temperatures get up to 60Co. So this requirement is met.

b. Parts that are not within a casing should have a lifetime of at least 20
years in a desert environment. Most parts and piping are made from stainless steel, assumed is that for these parts, it will not be a problem to meet this requirement. The absorption column is made of plastic. It is assumed that this part can be designed to have a lifetime of over 20years. For the wires and the sensors, it is expected that these can also be designed to meet the lifetime requirement. This can be done by adding wire protection and separate casings for the sensors.

Conclusion: assumed is that all the parts will meet this requirement or can be designed to meet this requirement.

Choosing layout 2 over layout 3 is an advantage because layout 2 is assumed to be cheaper. After all, it is made with less material. It is also assumed to be easier to make. Because the MS is part of the insulation module and is positioned on the back of the architecture design; therefore. Layout three will be more complicated to manufacture than layout 2.
To chose layout 2 over layout 3 one requirement should be met:
The insulation material should maintain its thermal properties for at least 20 years in a desert environment.

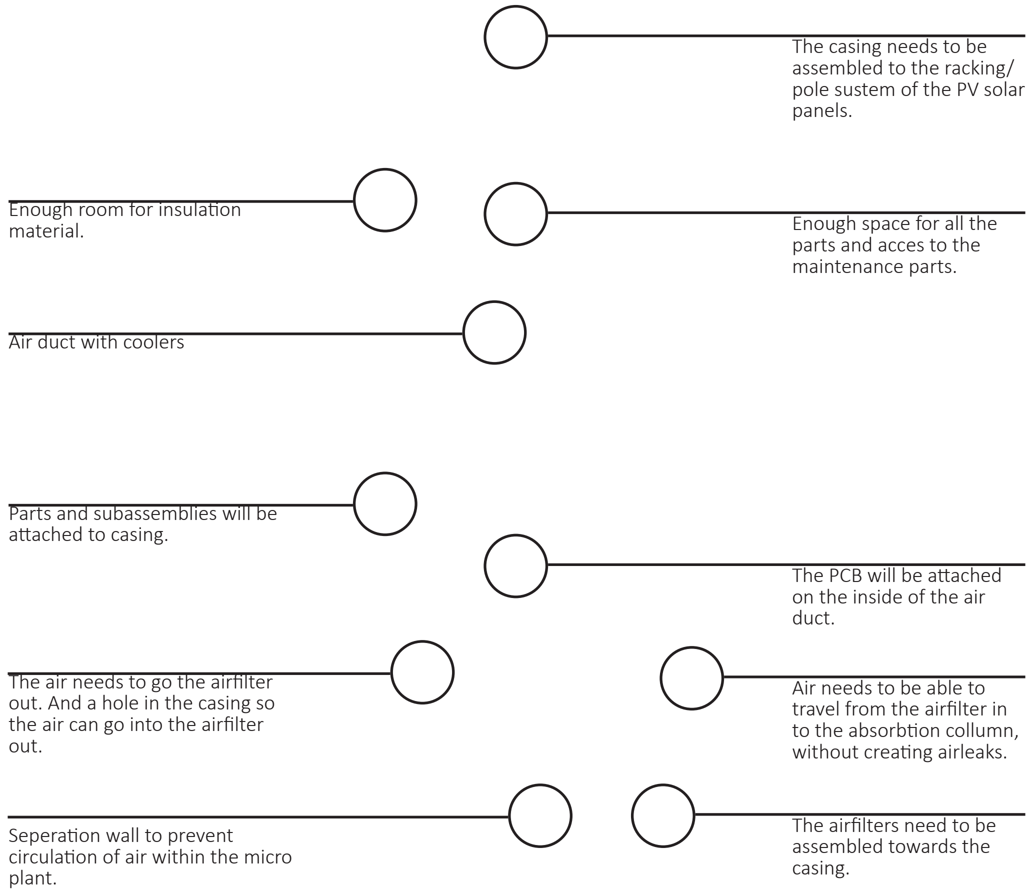
- Choosing an insulation material that is resistant to this environment.
- Packing up the insulation material.

Analysis in §6.4 illustrates that it is possible to have a layout that does not protect the insulation material. Therefor layout number 2 is chosen.

## 7.5 Casing functions

This paragraph answers the question: ***what are the core functions and limitations of the casing?***

There are some functions that every casing design needs to fulfill. Figure 7.4 illustrates the different functions a casing needs to fulfill, having layout number two in mind. The different functions that need to be fulfilled by layout two do not necessarily have to be fulfilled by one part or one production technique.






## 7.6 Production techniques

This paragraph answers the question:
Wich production techniques are suitable for the mass production of a casing for 100.000 micro plants?
The challenges are:

1. How to fulfill all the functions from §7.5?
2. How to suit a batch size of 100,000?
3. How to minimize investment risks?
4. How to support iterations?
5. How to minimize CapEx costs?

Table 7.1 illustrates different production techniques. The different techniques have a brief description of how suitable the production technique Is for the micro plant. The techniques are evaluated on how they can solve the challenges; this is done with an educated guess indicated with colors.

**Conclusion:** From the table, it can be concluded that rotomolding, sheet metal stamping, and thermoforming are not suitable for designing the micro plant. To further evaluate the four leftover production techniques, four basic concepts are generated in § 7. 7 till §7.10.

Legenda:
Excellent
Good
Average
Bad

| Process Challenges-> | 1 | 2 | 3 | 4 | 5 |
|---|---|---|---|---|---|
| **Injection molding:** Large injection mold parts require high investment costs. Multiple parts will be needed to fulfill all the functions. | Excellent | Excellent | Bad | Bad | Good |
| **Extrusion blow molding:** This process can create hollow parts. It is suitable for large products and large production volumes. | Good | Excellent | Good | Good | Good |
| **Rotomolding:** Rotomolding creates hollow plastic parts, like extrusion blow molding. The investment costs are way lower, but for this batch size, it is not suitable. For a smaller pilot batch, it could be useful. | Good | Bad | Excellent | Excellent | Bad |
| **Sheet metal bending:** Inverters also use sheet metal. It is used for numerous applications and can be suitable for the micro plant. However, metal is a precious material, and many secondary processes are needed to complete the part. | Good | Good | Excellent | Excellent | Average |
| **Sheet metal stamping:** Widely used in the car industry. Not commonly used to create hollow parts and not commonly used as the main stiff structure in a product. It cannot fulfill enough of the functions to be used in the design. | Average | Excellent | Bad | Bad | Average |
| **SMC:** Similar to injection molding. Stronger parts. Usually, a bit more expensive. | Excellent | Excellent | Bad | Bad | Good |
| **Thermoforming:** Can not create hollow parts. Cheap process. It can not deliver the stiffness or the hollow part for the air duct. Therefore it will not be used. | Bad | Good | Good | Good | Good |

*Appendix G2 sums up all the pro and cons of the following 4 concepts.*

*All the illustrations are a rough sketch of how the concept can look like , indicated in red without roundings. Calculations are made for a batch size of 100,000.*

*Note: all the cost prices in this report are estimates often based on an educated guess.  The goal of the prices is not to accurately calculate the cost price, but to estimate an order of magnitude that can guide design decisions.*

## 7.7 Concept 1.

Blow molded air duct with metal frame, blow molded air duct conly conducts the air, the metal frame fullfills the other functions. The blow molded air duct is made out of 2 parts that should be joined. The investment costs are estimations based on average plastic price of PP the weight of a CAD model and the assumption that the process and other costs equals the plastic price.  The metal frame price is an estimation based on the assumption that the price will be 1/4 concept 4.

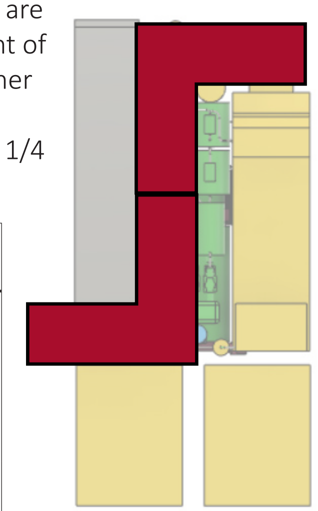


Figure 7.5 Sketch concept 1.

| | Investment cost | Secundairy processes | Assembly |
|---|---|---|---|
| **Blow molding** | 50.000 € mold<br>8 kg PP<br>1.5 €/kg<br>12 € pp<br>12 € process<br>total: € 24,50 | Pipeline holes<br>Airduct holes<br>Metal frame production | 1. Coolers in airduct<br>2. Join airduct<br>3. Attach metal frame<br>4. Attach subassemblies to metal frame. |
| **Metal frame** | € 15 | | |

Table 7.2 Concept 1 details

## 7.8 Concept 2.

2 Injection molded parts that form the air duct and the structure. The investment costs are based on information from and interview with HSV (2020). The weigt of the product is obtained from a CAD model. The assumption is made that the process costs equals the material costs.

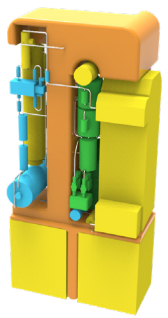


Figure 7.6 CAD model

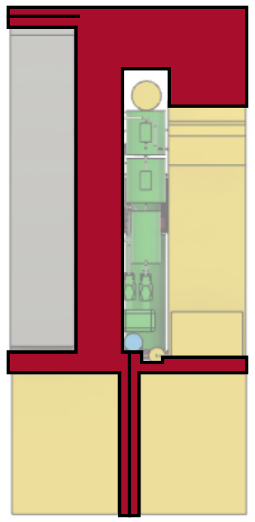


Figure 7.6 Sketch concept 2.

| | Investment cost | secundairy processes | Assembly |
|---|---|---|---|
| **Injection molding** | € 1,000,000 mold<br>PP 1.5 €/kg<br>10 kg PP.<br>€ 15 material<br>€ 15 Process costs<br>Total  € 35 | Attachment between two parts. | 1. Coolers in air duct<br>2. Close air duct<br>3. Attach parts to air duct. |

Table 7.3 Concept 2 details



## 7.9 Concept 3.

The SMC design is quite similar to the injection mold design. Except for that SMC is a stronger material and therfor SMC requires less ribs. The mold costs are similar to the injection molding. Secondairy processes and assembly are also similar.

| | Investment costs | secundairy processes | Assembly |
|---|---|---|---|
| **Injection molding** | € 1,000,000 mold<br>SMC 2 €/kg<br>10 Kg SMC<br>€ 20 material<br>€ 20 Process costs<br>Total:  € 40 | Attachment between two parts. | 1. Coolers in airduct<br>2. Close airduct<br>3. Attach parts to airduct. |

Table 7.4 Concept 3 details

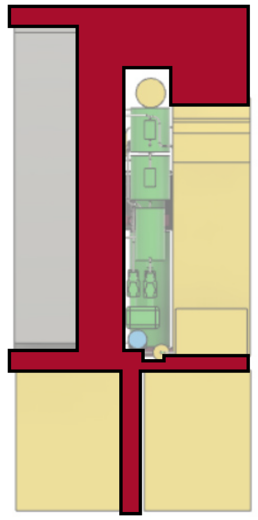


Figure 7.7 Sketch concept 3.

## 7.10 Concept 4.

The structure and the air duct is made out of sheet metal.

Figure 7.6 CAD model

| | Investment cost | Need for secundairy processes | Assembly |
|---|---|---|---|
| **Sheet metal** | € 60 (Sophia software) | Close openings to create a leaktight airduct. | 1. Coolers in airduct<br>2. Close airduct<br>3. Attach parts to airduct. |

Table 7.5 Concept 4 details

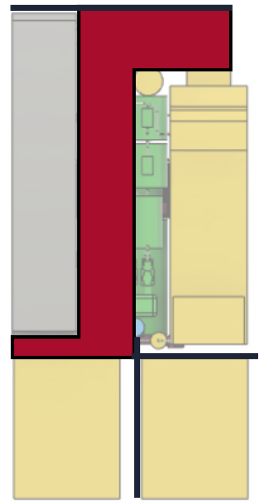


Figure 7.8 Sketch concept 4.

## 7.11 Evaluation

**Selection criteria 1: Environmental impact**
After a lifetime of 20 years, it needs to be possible to recycle the air duct/ casing. Otherwise, ZEF, creating sustainable energy, will end up with 100,000 pieces of non-recyclable parts. Assume this part was 10 kg, ZEF would end with a million kg of non-recyclable material.
Concept 1 and 2 use plastic; this can be recycled if a plastic without additives is used. Additives like glass can increase the stiffness of a product; other additives can make the product more UV resistant.
Concept 3 uses SMC; this is a composite material that can only be downcycled. Therefore this material and production method will not be used. Concept 1 and concept 4 use metal, metal can be recycled.

**Selection criteria 2: functionality; How to fulfill all the functions from §7.5?**
The concept should be able to fulfill the functions as described in §7.5. The essential functions are the transportation of air and adding structure to the design.
Concept 1: The blow-molded part can fulfill 1he function of transporting air. The metal part can fulfill the function of providing structure.
Concept 2.: The injection molded part is well suitable for the transport of air. Because it is not possible to use glass-filled plastic, it is not sure if an injection part alone can fulfill the structural function of the air duct/ casing. Because this can be a bottleneck in the design, it is advised not to use injection molding.
Concept 4.: The metal frame is suitable to structure the micro plant parts. The metal frame needs secondary processes like closing the seams to leak-tight the air duct.

**Selection criteria 3: Part cost price and investment costs.**
Most part prices are quite similar.
Concept 1: The metal frame does not require significant investment costs. The investment cost of the mold is assumed between S0.000 and 100.000 €. This is 10% of the investment cost of an injection mold. In a batch size of 100.000 items, this is 1 euro per item.
Concept 2. The investment costs of an injection mold and the risk is high. If other alternatives do not involve this risk, this is a better option. Therefore it is not advised to use injection molding for the casing.
Concept 4: There are no significant investment costs. However, the part price of a metal air duct is assumed to be higher than other concepts.

Table 7.6 summarizes the findings from the evaluation.

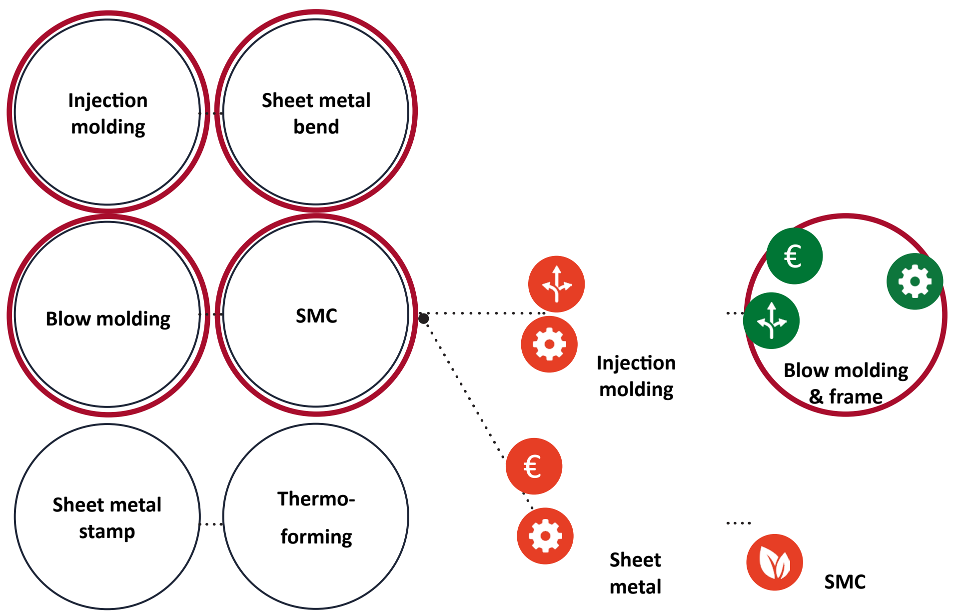
| | Recyclable | Stifness | Flexibility to change design | Investment cost | Part price |
|---|---|---|---|---|---|
| Concept 1 | Yes | High | Average | Average | Lowest |
| Concept 2 | Yes | Low | Low | High | Average |
| Concept 3 | No | Average | Low | High | Average |
| Concept 4 | Yes | Average | High | Low | Higest |

Table 7.6 Concepts evaluation



## 7.12 Conclusion

Concept 1 will be chosen to elaborate on further. Expected is that it is the most inexpensive concept because it is a hybrid solution for each functionality. The blow-molded air duct is expected to be the cheapest way to make an air duct, sheet metal or injection molding is expensive. A blow-molded airshaft also better fulfills the function than a sheet metal air duct where many openings still need to be closed. The metal frame provides the structure; this is more suitable for this function than a virgin plastic part that might deform under high temperatures and a heavy load over a long time.




### Key takeaways

- A closed casing is not required.
- An open structure is supposed to be cheaper than a closed casing.
- The most important functions of the casing are:
  - Transporting air
  - Creating structure
- Options for the casing are: Blow molding with metal frame, injection molding, SMC, sheet metal.
- Important desision drivers where: sustainability; can the material be recy-cled after its lifetime, feasibility of function fullfillment and costprice versus investment price.
- It is assumed that a solution with a blow molded air duct and a metal frame will best fullfill the most important functions for the lowest cost price, without the risk of making a big investment.

# 8. Final design

## 8.1 Introduction

The next few parapraghs descripe the final design of the micro plant. The design of the blow molded air duct, the frame, the assembly and the way that the product is transported. This design is the conclusion that derives from the considerations towards an embodiment design of the micro plant. This design is not ready to get produced like this. This design is the starting point that illustrates the questions that should be asked when designing the micro plant.

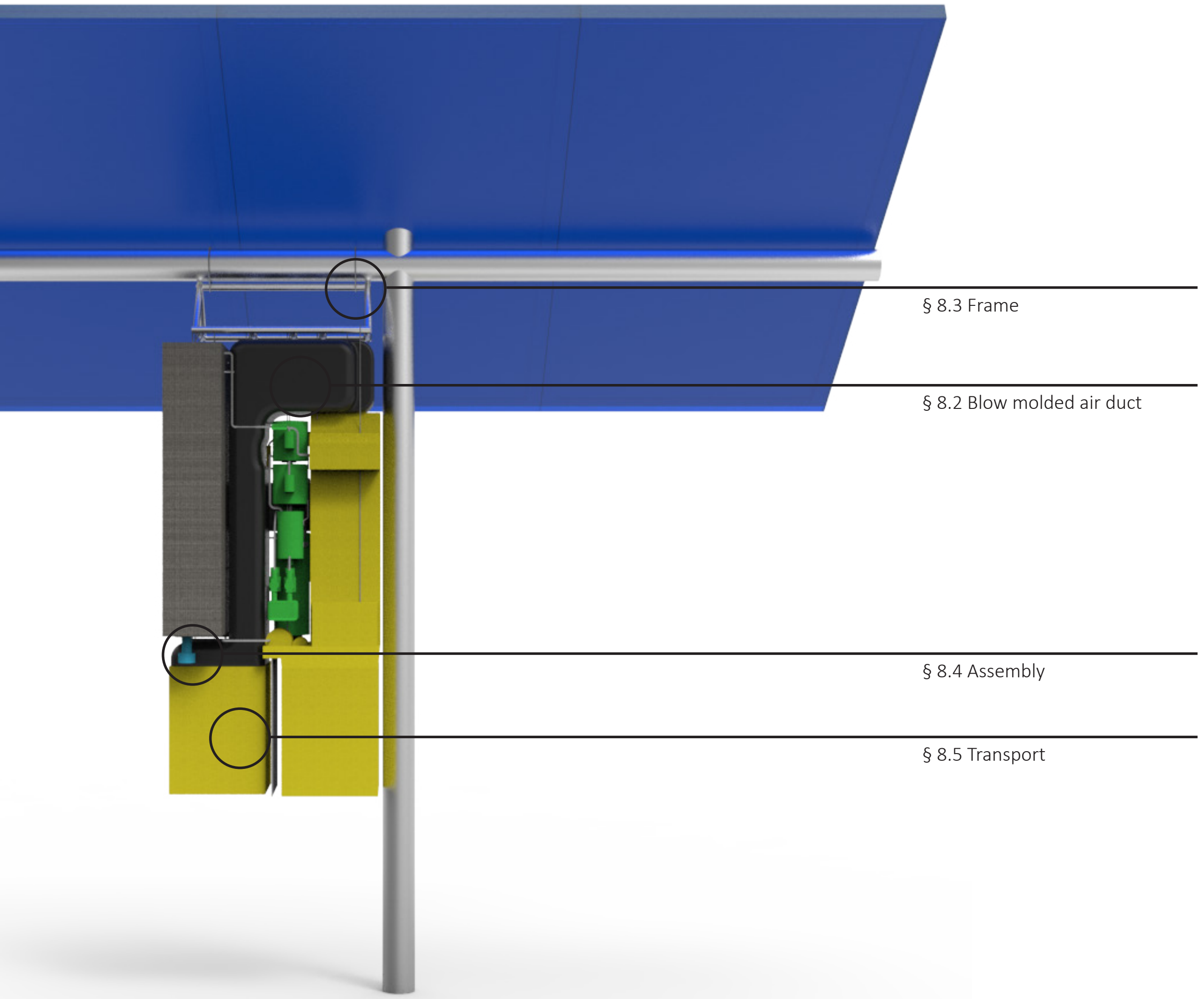
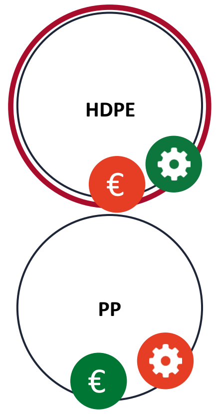



Figure 8.1 Sketch concept 2.



## 8.2 Blow molded airshaft

**Material:** Almost all commodity plastics can be used in the blow molding process. Zuiderplastics advises two different materials.
- HDPE or PP
HPDE is more expensive but has more excellent wheater resistance than PP. HDPE has a more stable availability of the material than PP.
Additives: Additives that make the material unrecyclable can not be used. Carbon black is the most common additive to use as a UV protector. Carbon black is also a cheap and recyclable additive.
The purity of the material: in the airshaft's production process, waste material will be produced. This material can be recycled into new airshafts or treaded as waste. Making an airshaft from 100% virgin material has the advantage of better product and recycling properties; because the carbon chains get shorter each time the material is reused. The disadvantage is high material costs.




**Conclusion:** HDPE with carbon black will be used. Advised is to make a design that has a minimum of waste so the waste can be recycled into the production process of blow molding.

**Production process:** There are different ways to produce blow mold parts.

1. The most conventional way: This method is illustrated in figure 8.2. Extrusion blow molding is done with a parison (a hollow tube, usually round but with larger batch sizes it is also possible to make a profiled extrusion head) extruded from the top. It is possible to adjust the thickness of the tube over its length by controlling the extrusion head. After the extrusion, a mold encloses the parison. The mold clamps the desired shape. This clamp will create a weld seam at the places where the plastic is pressed together. A needle enters (usually from the bottom but in the illustration from the top) and blows the plastic toward the mold's surfaces. The product is cooled and extruded from the mold. The waste material will be cut, and optional secondary processes that fit within the cycle time can be done. Cutting

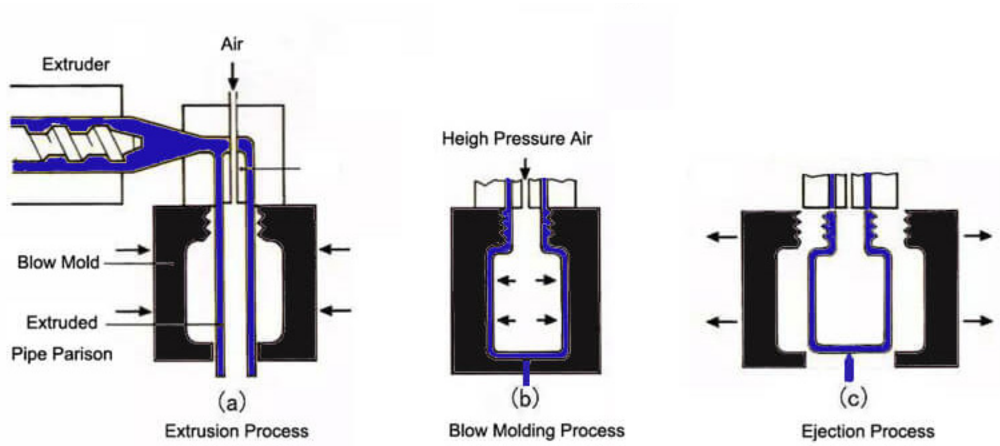



Figure 8.2 Extrusion blow molding advice (Alleych, n.d.)

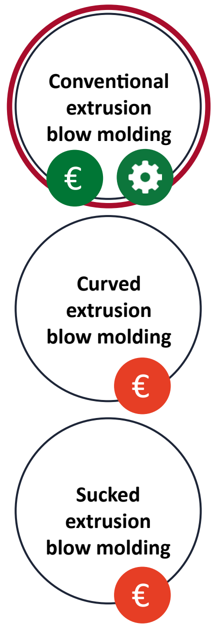

Figure 8.3 Before cutting


Figure 8.4 Curved

of the leftover material can be done with a punch or cut off with a knife. Figure 8.3 illustrates a product before the waste material was removed. Punching gives sharp edges; cutting does not leave sharp edges. Punching can be automated; cutting can not be automated.

2. An alternative way to create a product with a curve is when the parison can be cut from the extrusion head and laid into a mold with a particular bend. After closing the mold, a needle enters to blow mold the product. An advantage here is that a curve can be made without creating a residual flap. It leaves the parison intact without creating a weld seam between two sides of the parison. A disadvantage is that it makes the process more complicated and expensive. Figure 8.4 is an illustration of a product made with this type of production method.

3. In the automotive industry, the extruded parison is sucked into a mold of a particular shape. This allows for faster cycle times and gives the same type of results as with production process two.




**Conclusion**: Number one because it is a more straightforward production process and because it is accepted to have a weld seam. It is also a significant volume product to handle using production process two, only possible when this process is automated. Production process one also leaves flap that can be used to attach other parts too. It is also not possible or needed to create the whole airshaft in one final part, because it needs to be opened for the assembly of coolers.

**Design guidelines** (figure 8.5):

Figure 8.5 illustrates guidelines for the design of a blow molded part. The guidelines are further explained in appendix H.1

**Conclusion:** Figure 8.6, 8.7 and 8.8 illustrate the air duct design.



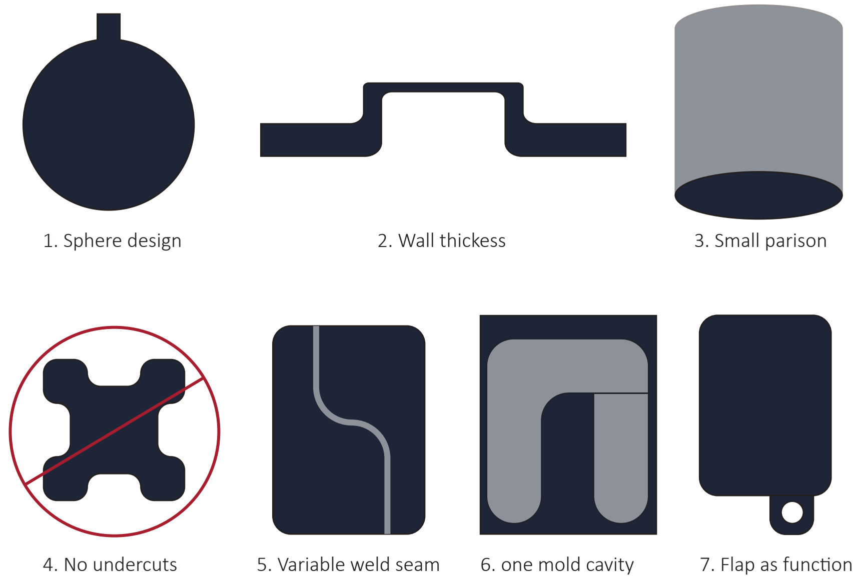


Figure 8.5 Design guidelines

**Cost price**

- **Mold:** With blow molding, the mold can be made from aluminum and is usually ten times cheaper than an injection mold. The assumed cost of this mold is €60.000. The mold price is affected by the material, size, and complexity of the mold. It also costs money to maintain a mold.
- **Material:** The price of HDPE is dependent on the oil price. the price usually ranges from € 1.20 to € 1.80. € 1.50 is a good average to use in cost price calculations.
- **Transport:** If the blow mold machine is not in the same building as the assembly line, the airshaft needs to be transported to the assembly line. Both Zuiderplastics and Dr. Ir. Tempelman pointed out that transport is often a high overlooked cost.
- **Machine costs:** within the machine hour price, there are among others: wages for one man operating the machine, depreciation of the machine, power usage, and maintenance of the machine. The machine costs within zuiderplastics vary from 25 to 60 euros per hour. A machine can usually make 20 to 90 products an hour. It is assumed that the airshaft is made with a large, expensive machine.
- **Secondary processes:** All the secondary processes that can be done within the cycle time by the woman operating the machine are covered within the machine costs and thus free. The secondary processes are punching, drilling holes for the pipes, the air filter, and the air fan. It is assumed that punching and drilling holes for the air filters and air fan can be made within the cycle time. The holes for the pipes need to be done in post processes. It is assumed that one man can do 30 air ducts an hour. If more elaborate machines like CNC cutting is used, than more expensive machine costs are calculated. Not all companies want to do manual secondary processes; some will create a fully automated production line, using robots. For the production of 100,000 pieces, this is the most realistic scenario. For a pilot, manual labor is realistic.

- **Overhead costs:** a blow mold company needs to cover its costs for among other things: housing, offices, and services. These costs vary from 15 to 30% extra costs. It is common to do 20 to 25% extra.
- **Profit of the blow mold company:** The blow mold company uses a profit margin of, on average, 17%. However, some markets use a profit margin of 6%. This will be depended on the type of blow molder ZEF will cooperate with.

**Conclusion:** The cost price is calculated to be 16 euro per airshaft (figure 8.9 and table 8.1). The calculation spreadsheet can be found in the appendix fixme. Figure fixme illustrates the costs per category.

Figure 8.6 Blow molding parison

Figure 8.7 Air duct context

Figure 8.8 Air duct design



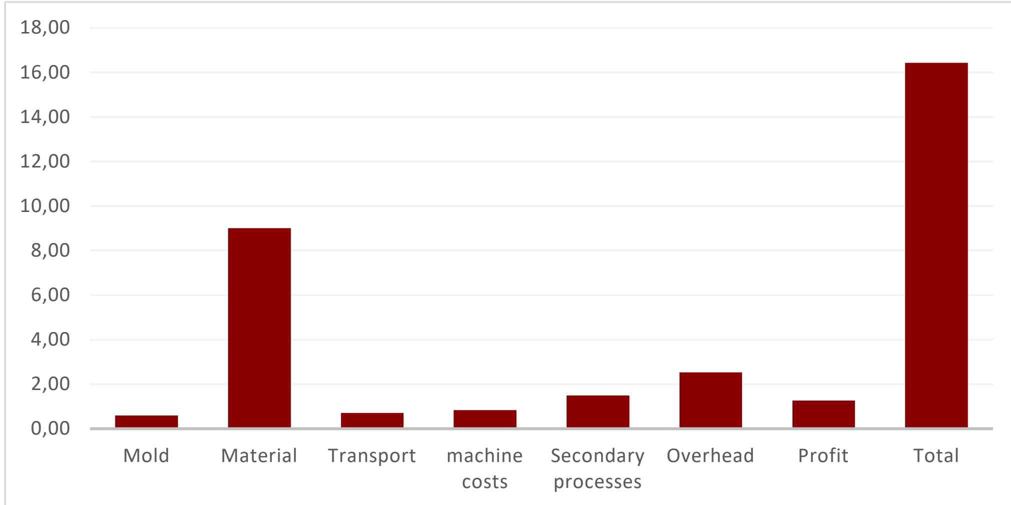



Figure 8.9 Cost price

| | | | | |
|---|---|---|---|---|
| **Indirect variables** | | | | |
| Cycle time | 60 | seconds | | |
| Pallets per truck | 33 | | | |
| Products per pallet | 30 | | | |
| Secondary processes | 30 | product per hour | | |
| Weight per product | 6 | kg | | |
| Batch size | 100000 | | | |
| | | | | |
| **Direct variables** | | | | |
| Mold | 60000 | € | 0,60 | €/micro plant |
| Material | 1,5 | €/kg | 9,00 | €/micro plant |
| Transport | 700 | €/truck | 0,71 | €/micro plant |
| machine costs | 50 | €/hour | 0,83 | €/micro plant |
| Secondary processes | 45 | €/hour | 1,50 | €/micro plant |
| Overhead | 20 | % | 2,53 | €/micro plant |
| Profit | 10 | % | 1,26 | €/micro plant |
| **Total** | | | 16,43 | €/micro plant |

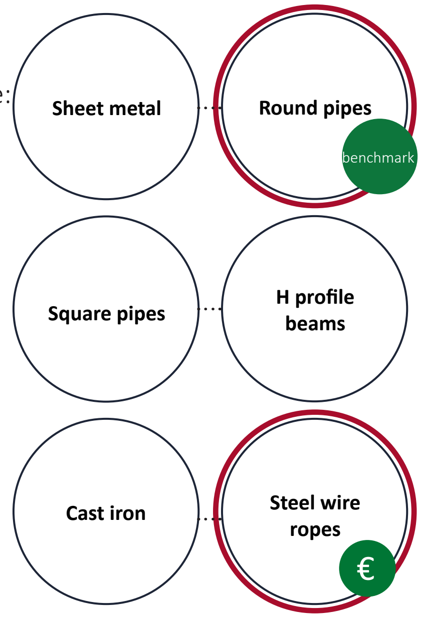
Table 8.1 Cost price

## 8.3 Frame

The function of the frame is a base where all the parts can be attached to as well as attaching the whole micro plant to the rack system of the PV solar farm. The frame is the backbone, stiffness, and structure of the design. Figure 8.11 and table 8.2 illustrates the loads that the frame needs to endure. The weights are estimates based on data from the CAD file. The weight of the frame is 5kg resulting in the total weight for the micro plant of 80 kg.

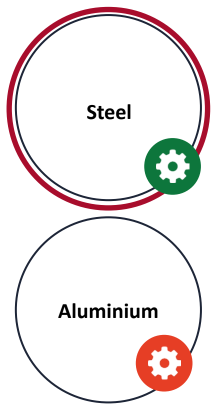
**Shape:**
There are different ways to make a metal frame:

- Sheet metal frame
- Round pipes
- square pipes
- H profiled beams
- Cast iron




A benchmark of products that use a metal frame (figure 8.10) for construction points out that round pipes are most commonly used to create a cheap and stiff construction. Round pipes can, among other things, be found in bikes, furniture, and scaffolding.
Square pipes can, among other things, also be seen in furniture and ladders. Sheet metal frames can be seen in small products that do not require a heavy load, H profiled beams can often be seen in massive building constructions.
Conclusion: round scaffolding pipes will be used for the construction of the micro plant.

**Material:** The metal needs to be recyclable and be able to maintain 20 years lifetime. It is nice to use piping that is commonly available in the market, as well in diameter size as in material. Pipes are offered in steel and aluminum. Aluminium is lighter and more comfortable to mold. On the other hand, steel is stronger and cheaper. Bike



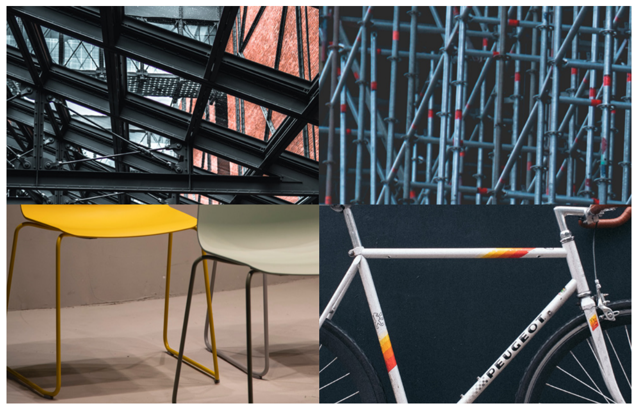



Figure 8.10 Benchmark products with a metal frame



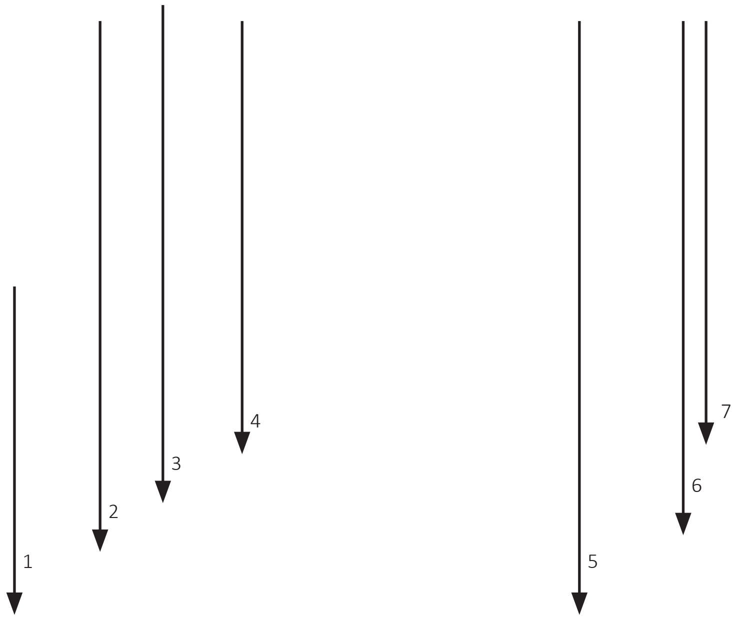



Figure 8.11 Loads

| number | Subassembly | Weight (kg) |
|---|---|---|
| 1 | Airfilter | 0.5*2=1 |
| 2 | Airduct and coolers assembly | 8 |
| 3 | FM assembly | 20 |
| 4 | Absorbtion collumn assembly | 20 |
| 5 | Desorbtion assembly | 5 |
| 6 | AEC assembly | 11 |
| 7 | MS assembly | 10 |
| | **Total** | **75** |

Table 8.2 Loads

frames are, for example, offered in both aluminum and steel. It is hard to weld steel to aluminum and vice versa. Because most of the parts in the micro plant are made from steel, the pipes will also be made from steel.

Steel wire ropes: Piping is thick and requires space. Steel wire ropes are extremely strong, but they are not stiff. At places where only strength is needed, steel wires will be used. Steel wires are cheaper, easy to assemble, small and strong.

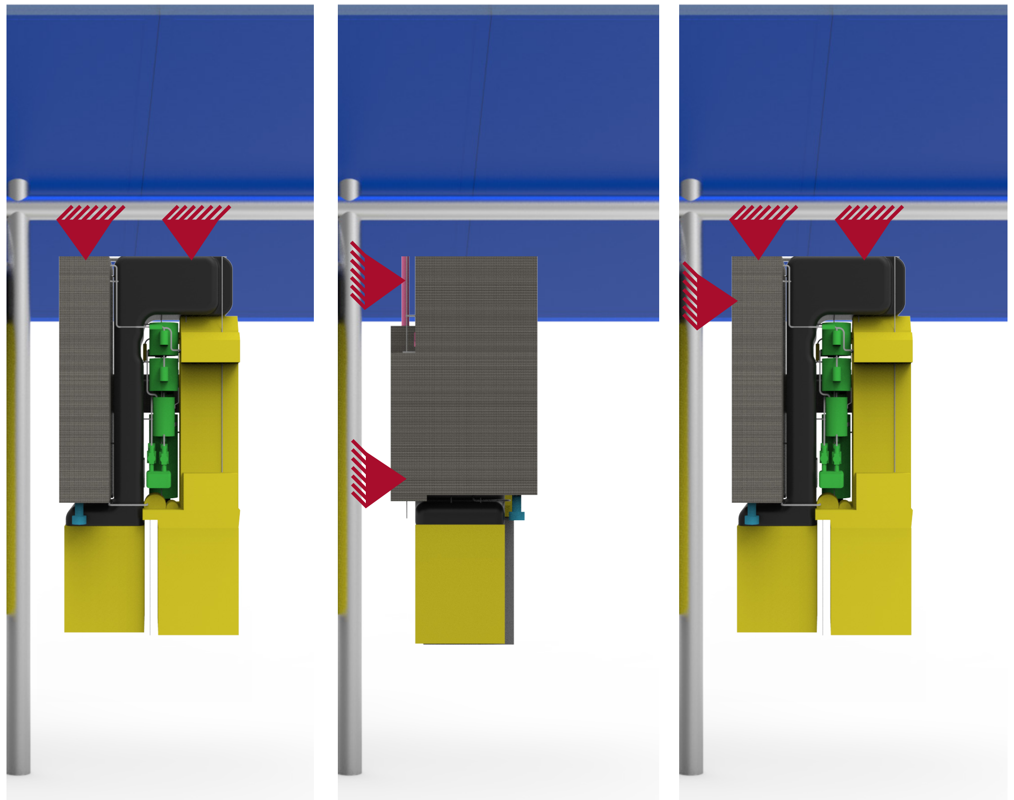


Figure 8.12 Shape of the construction

**Conclusion:** steel

**Attachment to the PV solar panel racks:** The micro plant can be attached to vertical, horizontal, or both beams of the rack. The place where the micro plant is attached to influences the design (figure 8.12).

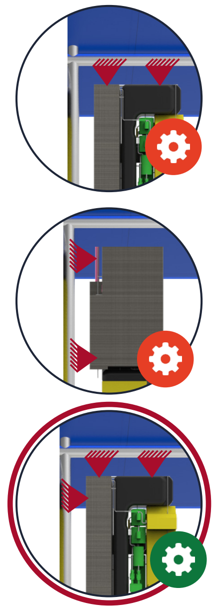
1. **Vertical beam:** the vertical beam is the most obvious choice since invertors and previous designs of the micro plant were all attached to this vertical beam. If the micro plant will be attached to the vertical beam, it is best to have it attached at two places—attachment to the vertical beam results in bending forces. Particular attention should be paid to the stiffness of the construction.
2. **Horizontal beam**: Assumed is that the farm also has vertical beams. There is a 10% chance that these horizontal beams do not exist; this could be when using tracking PV solar panels. Haning the micro plant creates a pulling force instead of a bending force. Hanging the micro plant can be interesting because it requires less metal for the stiffness of the construction. Haning the micro plant can also be attractive for the assembly of micro plants on the farm.
3. **Both beams:** If the micro plant is hanged, it is a hinge, not a fixed connection. If the micro plant would be attached to both the horizontal beam and the vertical beam, it can use the advantages of both options. Having the force distribution of the horizontal beam and preventing the hinge using the vertical beam.

**Conclusion:** using both beams for the construction.

**The shape of the construction:** The goal is to create the optimal necessary stiffness



with the least amount of steel piping necessary. To minimize steel piping subassemblies are hanged to the construction on top using steel wires. The construction on top is a triangle construction with pipes connecting both sides for the steel wires' attachment. A triangular shape is chosen because this is the stiffest construction one can get. An example of a product with a similar shape and function is a clothes hanger; this product also needs to be stiff and be made with the least amount of material to handle similar loads, although from different sizes. The triangle is similar in size on every length. This length is for assembly and manufacturing purposes.
The steel cables are connected to the frame with cable clamps. The frame is connected to the rack using metal hose clamps. Figure 8.13 and 8.14 illustrate the final design of the frame.



**Price of the frame**: For a rough indication of the price of one frame, a calculation is made in table 8.3.

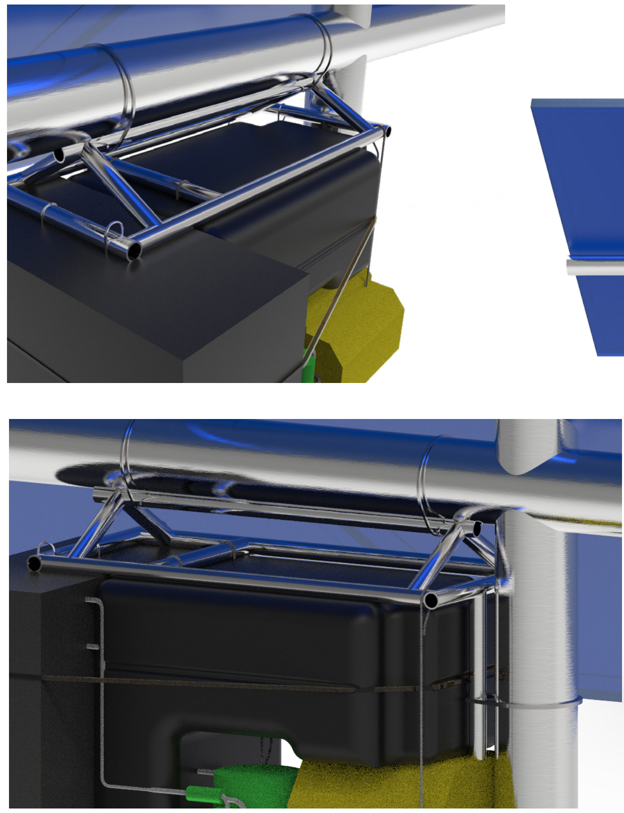


Figure 8.13 Final design frame- close up

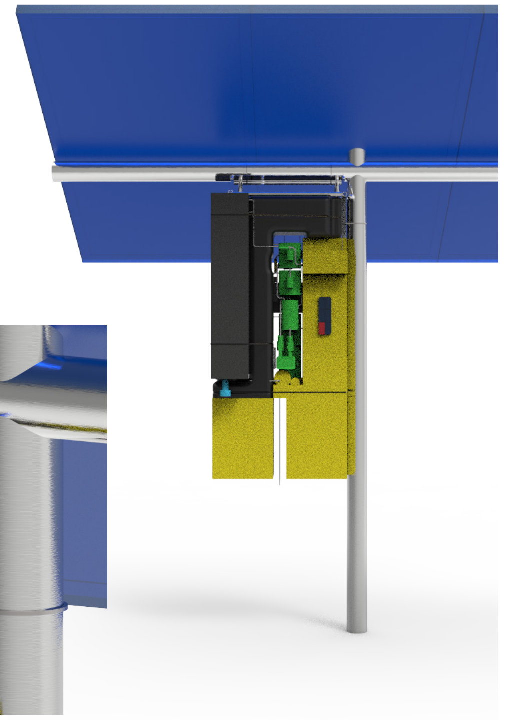


Figure 8.14 Final design frame- front view

| | |
|---|---|
| 4 m pipe | 1.50*4 = € 6 |
| Welding costs | € 2 |
| Metal cables and clamps | € 4 |
| Attachment to rack 2 metal hose clamps | € 2 |
| **Total cost** | **€ 14** |

Table 8.3 Cost price metal frame

## 8.4 Assembly

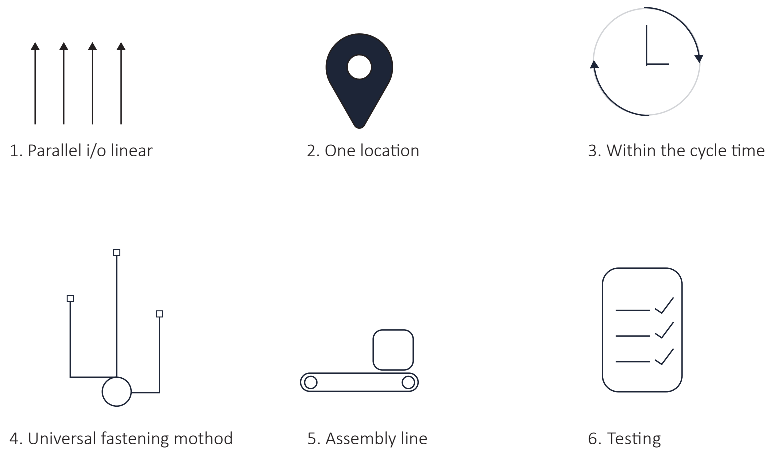
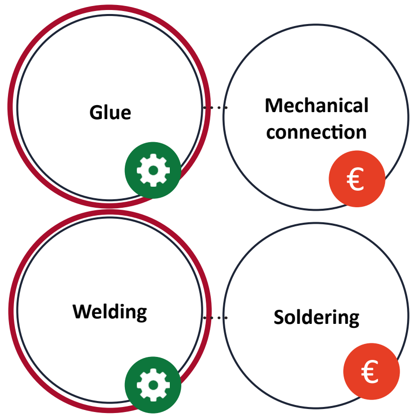



Figure 8.15 Assembly guidelines

**Assembly guidelines:** For the assembly of the micro plant, some basic design guidelines and their implementation for the assembly of the micro plant are formulated in Appendix H.2. and illustrated in figure 8.15

**Connections between parts and piping:** All the parts need to be assembled using 6mm stainless steel piping. These piping needs to be connected. There are several ways to do this:




- Mechanical connection
- Soldering
- Glue
- Arc welding (plasma, TIG, MIG, laser)

**Conclusion:** The connection between the pipes and the parts can permanent. Requirements are:

- The connection can handle a force of 50 Barr.
- The connection is always leak-tight.

Arc welding is an obvious choice to use for subassemblies. However, arc welding happens at temperatures that will harm the operation of sensors and destroys plastics. Only parts that are entirely made out of hot resistant materials (>800 oC) can be welded. However, advised is to stick to one fastening method. Expected is that a mechanical connection is most expensive since this requires fasteners. The other two options are soldering and glue. For now, assumed is that glue will be used for the connections that can not be welded.

**Subassemblies:** guideline one teaches first to make subassemblies in a parallel way and then, in the end, assemble the subassemblies into one final assembly.



Subassemblies are composed of parts that are required to be together because of the piping connections between them because of their place in the architecture design and because of testing the subassembly. Designing the product for assembly required some changes in the architecture design.

Figure 8.16 illustrates the assembly tree. All the numbers have corresponding parts (appendix C). The assembly tree does not illustrate when parts get their piping connections.

Figure 8.17 illustrates the assembly with their rendered parts. This illustration shows how the subassemblies are one stiff part before they get together in the larger assembly.

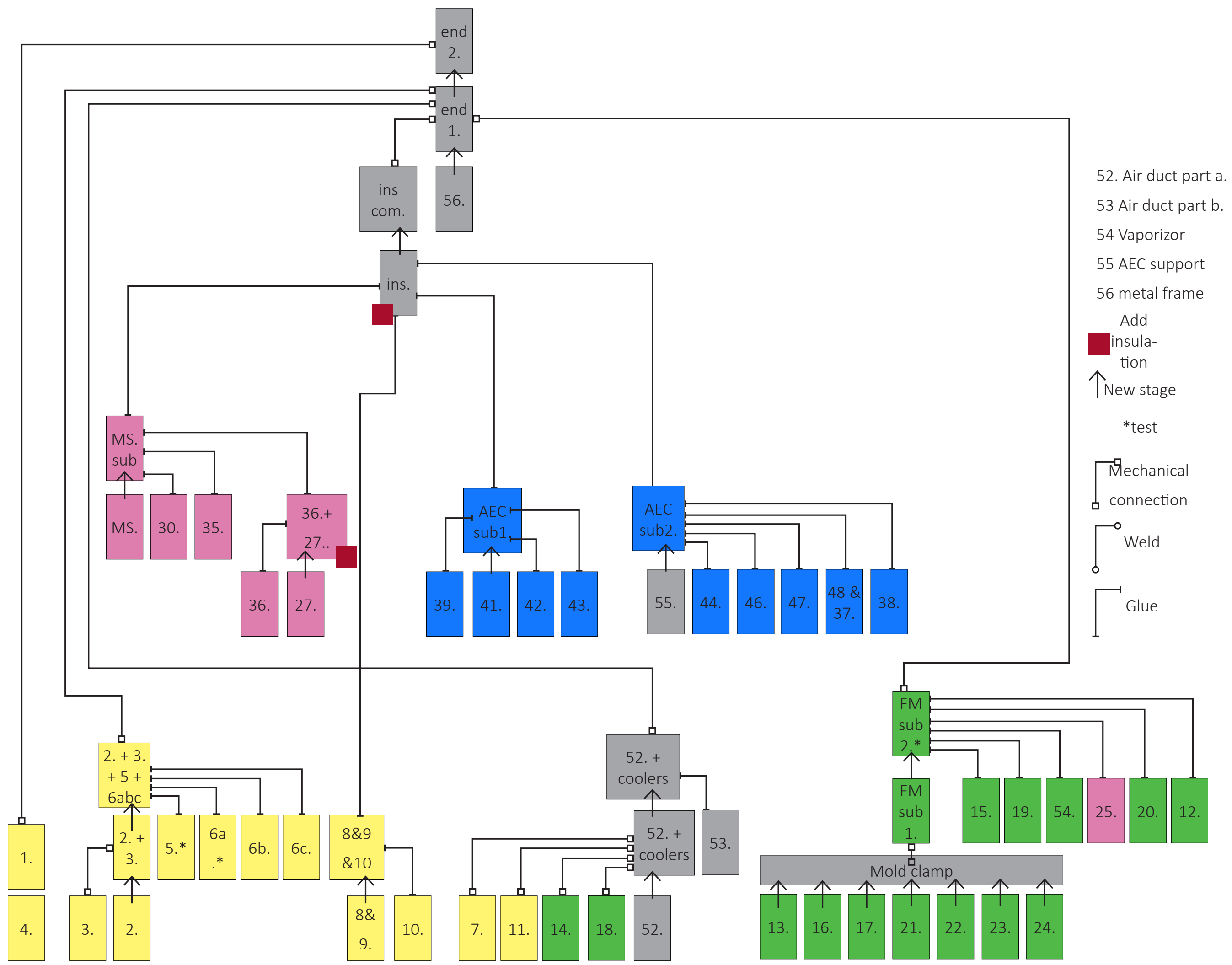



Figure 8.16 Assembly tree

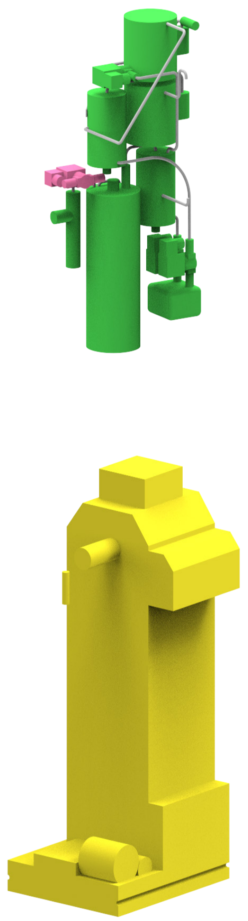


Figure 8.17 Assembly (sub) parts



# 8.5 Transport

**Transport requirements:**

- The whole construction needs to be stiff for transport in a container to the farm location.
- The construction needs to be stiff for transport from the container to its operating location.

Assumed is that transportation within the farm is done with small vehicles like a forklift or a small tractor. Assumed is that during transport, the air filters are compressed in size (figure 8.18).

**Costs:** Transport costs money. When the micro plants are shipped from Europe to the location where the farm is built, this requires money.

| | |
|---|---|
| Transport within europe from A to B with a truck | € 700 |
| Pallets per container | 33 |
| Micro plants per pallet (figure 8.19) | 2 |
| Transport costs per micro plant within europe | €10.60 |

Table 8.4 transportation costs within europe

€10.60 is significant money per micro plant (table 8.4). This price is probably higher when the shipment needs to be outside of Europe. Therefore it is advised to check if and how more micro plants can fit on one euro pallet. Sizing could, for example, be done by reducing the size of volume determining parts, these are significantly significant parts, so their size determines the volume of the product (MS, stack & absorption column)

**Transport packaging:** During transport, the product is most likely packed to prevent harming the product.

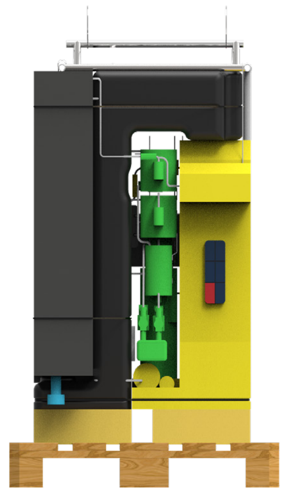


Figure 8.19 Amount of micro plants fitting on a pallet

Figure 8.18 Reduced air filters

## 8.6 Conclusion

This conclusion fulfills the objective: *''To design a casing that can fulfill its core functions.''* and answers the research question: What are the micro plant properties and the main shape of the casing?

Figure 8.20 illustrates the conclusion.

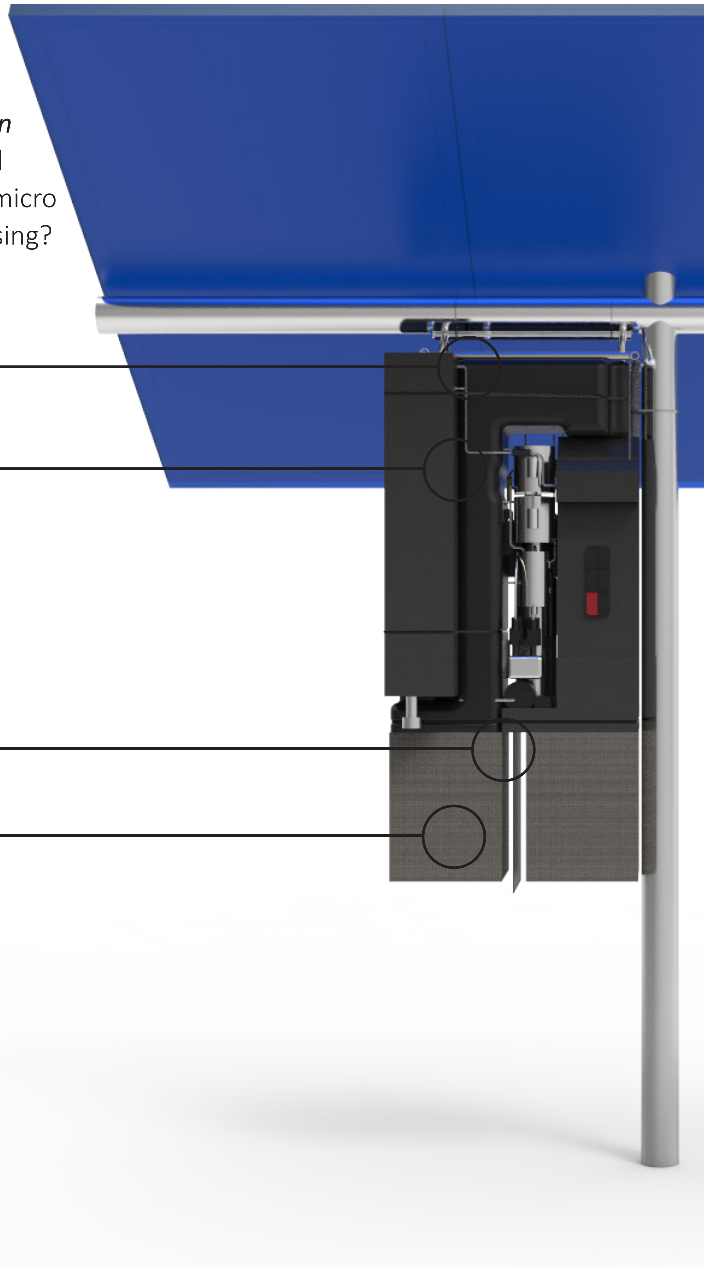



Figure 8.20 Conclusion embodiment design

### Key takeaways

- The blow-molded air duct can also be used to attach parts too.
- Hollow steel pipes are used for the frame, based on a benchmark analysis.
- Assembly to the rack system of the PV solar panels is both to vertical and horizontal beams, to prevent momentum and use the benefits of tensile strength.
- Attachment of parts to the frame is done with steel wires.
- Assembly influences the architecture design. The next designer should take assembly already into account when considering architecture design.
- Transport is a high cost. Reducing the size of some large parts could result in fitting more than two micro plants on one euro pallet.
- Transport influences the stiffness the design needs to have in different directions; it needs to be stiff from all sights.



# 9. Discussion

## 9.1 Product level

**Program of requirements:** A full evaluation of the existing program of requirements can be found in appendix fixme. Main takeaways are formed using the four design drivers:

**Cost:**

| | |
|---|---|
| Assemed cost per kilo of products | 10 €/kg |
| Weight of the micro plant | 80 kg |
| Micro plant cost price | €800 |
| Micro plant price per PV solar panel | €150 |
| Amount of solar panels | 3 |
| Total planned price of the solar panel | €450 |
| Difference | €-350 |

The micro plant is € 350 more expensive than planned. This cost price means that the micro plant should be designed cheaper, be designed for a bigger number of solar panels, or the micro plant is not feasible.

**Sustainability:** Two major evaluation points:

- 20 years lifetime

A 20 years lifetime under hot desert circumstances is hard to evaluate. Assumed is that all the stainless steel parts can easily withstand the environmental conditions. All plastics parts will be black using carbon black, this will minimize the UV impact on the material, without changing its recyclability. Another consideration in the design of the micro plant is the impact of transport on the plant. Especially connections between parts need to be 100% leak-tight, before and after transport. This is a new requirement learned from § 8.5. Advised is to test the micro plant prototype in a weather simulator before starting with the investments required for mass production.

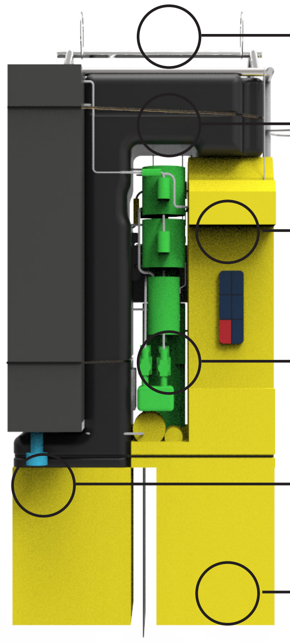
- End of life scenario

If a farm is written off after 20 years, there are fixme micro plants with valuable materials. These materials should be recycled. Therefore it is essential to:
Use recyclable materials
They are easing the process of sorting materials by minimizing the number of materials used in the design and allow for disassembly.
Report on the materials and how to disassemble them.

**Flexibility:** The design must fit with the growth strategy of ZEF. Meaning that:
Does the investment allow for easy iteration?
Does the design allow changes on a part level?
This is done by choosing production methods that do not require high investments and design guidelines that stay relevant in a changing context.

**Functionality:** The design is feasible when the design fits the mass production of 100,000 pieces, including assembly and transportation.
The design of the micro plant is evaluated in figure 9.1.

**Existing technique of the micro plant:**
The design must fit the technique, but it should also fit the mass production and farm realization. Therefor a step by step guideline is created that can be used by ZEF when engineers need to design the parts of the micro plant for the next TRL levels.



**Frame:** The optimal shape of the frame is too insecure at this point. This design needs optimization. A benchmark proves the feasibility of a metal frame.

**Air duct:** The design of the air duct is still quite conceptual. The design requires more engineering to make it feasible for production. This design illustrates what functions the part should have and how this can be embodied.

**Absorption column:** the absorption column fulfills more functions in the design than its core function. The flexibility in size and shape of this part has a significant influence on the total design of the micro plant. More research should be done on the feasibility of adding these extra functions.

**Maintenance:** the basic principles of the maintenance are feasible: on place, predetermined, planned maintenance. Parts are not designed yet with the end product's maintenance; the feasibility of this maintenance requires proof.

**Insulation:** Stone wool is a feasible solution, but the production technique of the part requires research. The protection layer is assumed to last for 20 years in the desert, and this must last and is not proven at this point.

**Assembly:** the research only touches the surface of the assembly. Research is needed to prove the feasibility of the design in detail. Assembly has already proven to be of significant influence on the design.

Figure 9.1 Technique evaluation



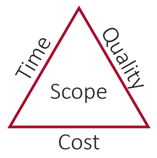



Figure 9.2 Constrains

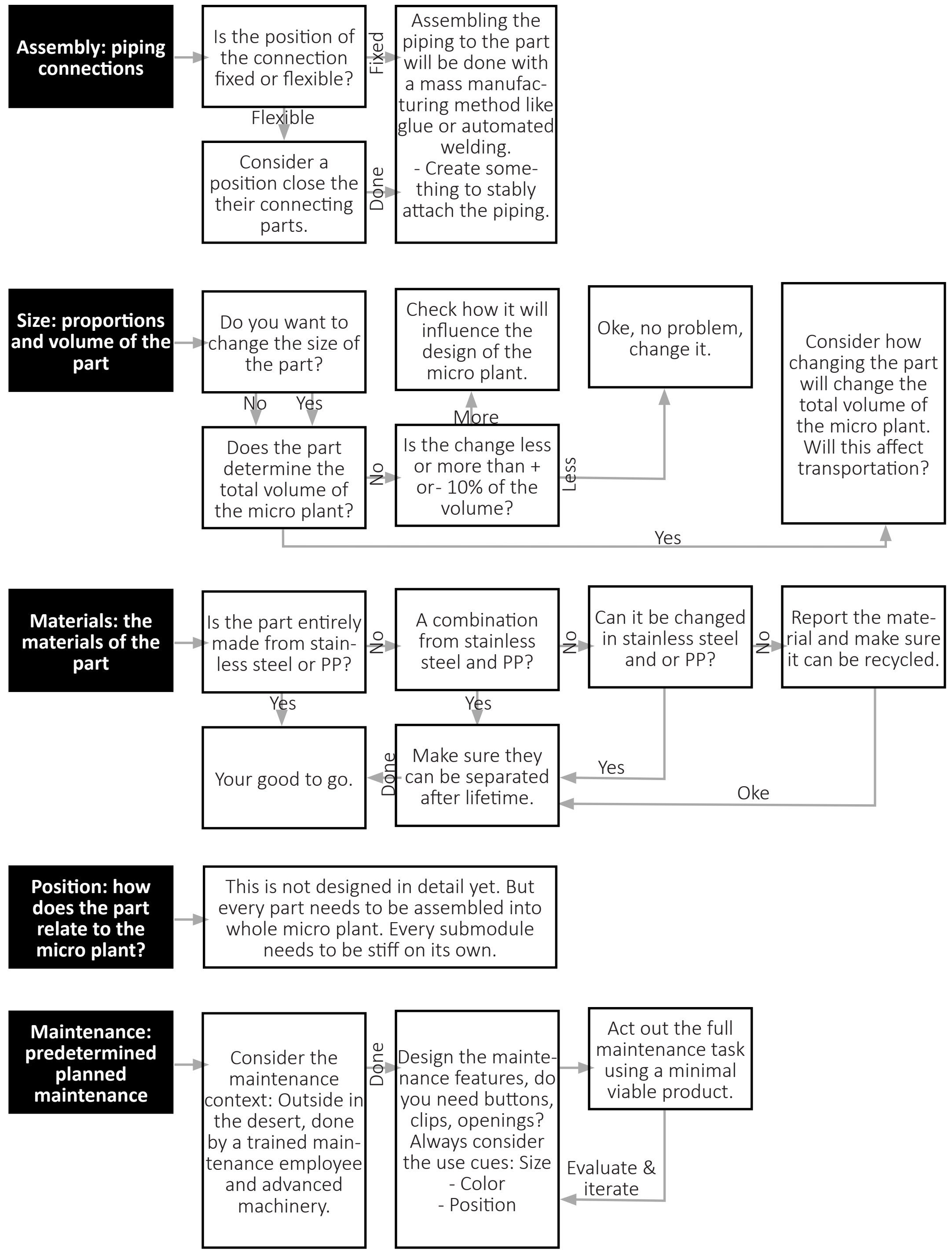



Figure 9.4 Design guidelines part engineering

## 9.2 Organizational level

**ZEF:**It was a positive experience working as a designer within ZEF. It is essential to know where to obtain the right information. It is challenging that technology keeps changing, and things are based upon assumptions. Therefore it is essential to set a fixed scope at a particular moment in the process.
Sometimes it is hard to communicate with stakeholders because there is little continuity within the team and the project. This can make it harder to keep stakeholders in the loop after having the first contact. On the other hand, this means an innovative environment with fast-developing new technologies.

**Designer approach:**The most critical challenges of this project for a designer can be summarized by the constrains triangle (figure 9.2). Many design decisions are still based upon assumptions. If the product's quality needs to be higher, this requires more time and/or cost. This project worked with a broad scope, little time, and little money resulting in a result that lacks the quality of an end product. The learning point is: have a clear goal, scope, and prioritize to avoid losing time digging into rabbit holes.

Maintenance research took much time while getting to the same conclusion would also have been possible with less in-depth research. This is because al the research was too much based on assumptions to use direct outcomes. The learning point is: Always look where to go and take the shortest path to get there.

Architecture design was done with physical foam blocks to search for the ideal shape and orientation of the parts. This process started before the COVID-19 outbreak; others had the change to give input as well. The team could have been more involved in the designing process by organizing more group sessions with the whole team. The learning point is: try to involve the team as much as possible in the design process.

Assembly was taken into account in a late stage of the design process. Assembly still influenced the architecture design. It was better to already take this into account in the invention of the architecture design. Now the assembly is based upon too many assumptions. The learning point: Identify effects that could influence the design early and incorporate these effects from the beginning.

Reporting was done from the beginning; however, in the beginning, everything that was reported instead of only reporting what is relevant for the reader. The learning point: safe time by being smart what to report and what not to report.

During the process, there was much contact with manufacturing stakeholders. Talking to people with expertise had proven to be a quicker and more effective way of obtaining information and feedback than searching for information on the internet or in papers. Sometimes this was a visit to a company or a phone call. The learning point: Always communicate with experts from an early stage.

From this project, it became clear that often value was not just in the design but in the considerations that led to the design. Learning point: It is important to make



considerations insightful.

Sometimes I jumped to a CAD model early, while a simple sketch would have been enough communication. A CAD model requires way more time than a sketch. The Learning point: always work with a minimal viable product to allow for quick design iterations.

This project was executed during the Covid-19 outbreak. Homeworking brought challenges concerning communication, motivation, and planning. Learning point: for me, working in a work environment benefits the result of a project.

**Future steps:** This design is highly conceptual and not finished to get to production. However, the design is a starting point for the full integration of technology, collaboration with companies, and a better understanding of the challenges that are still too come. To ensure continuity of the project, general planning for the product design is illustrated in figure 9.3.

**Influence on the technology:** The technology of the micro plant was integrated into

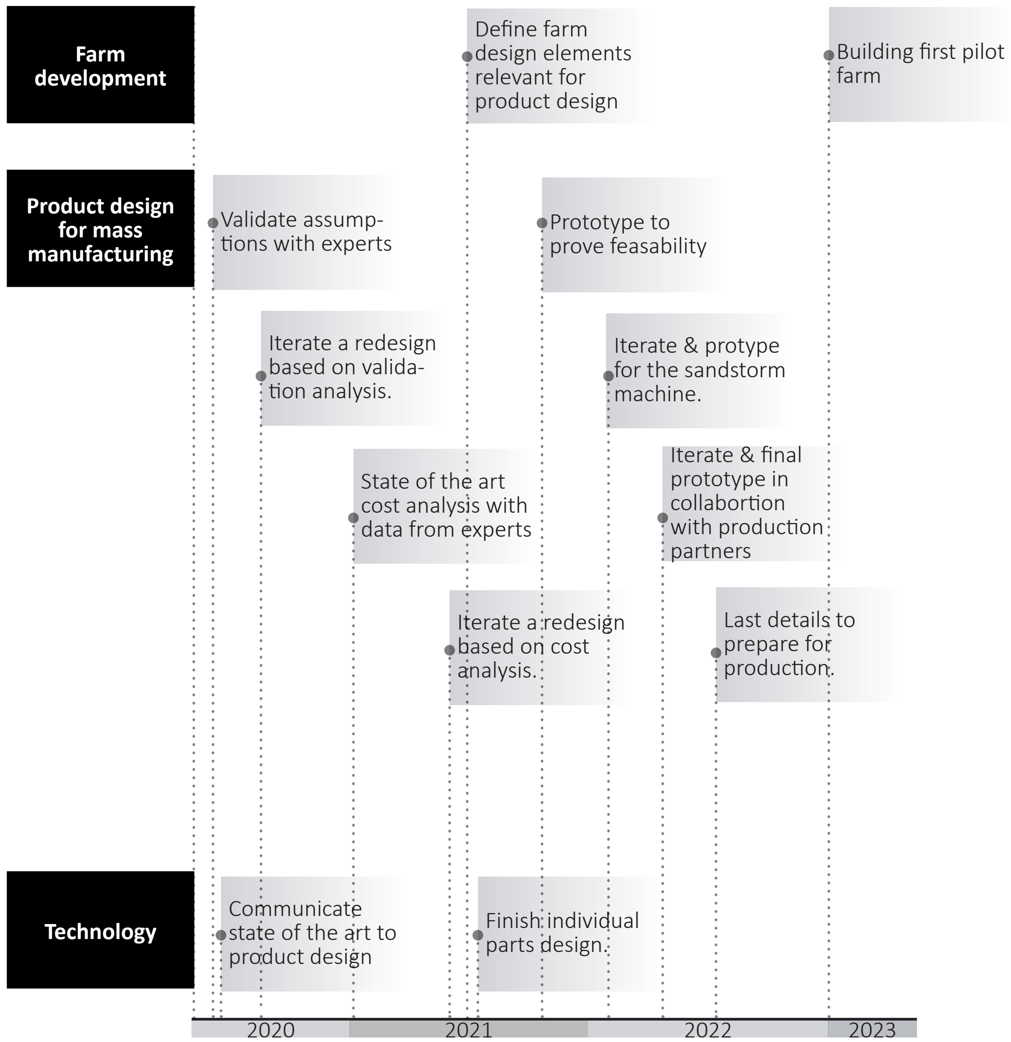


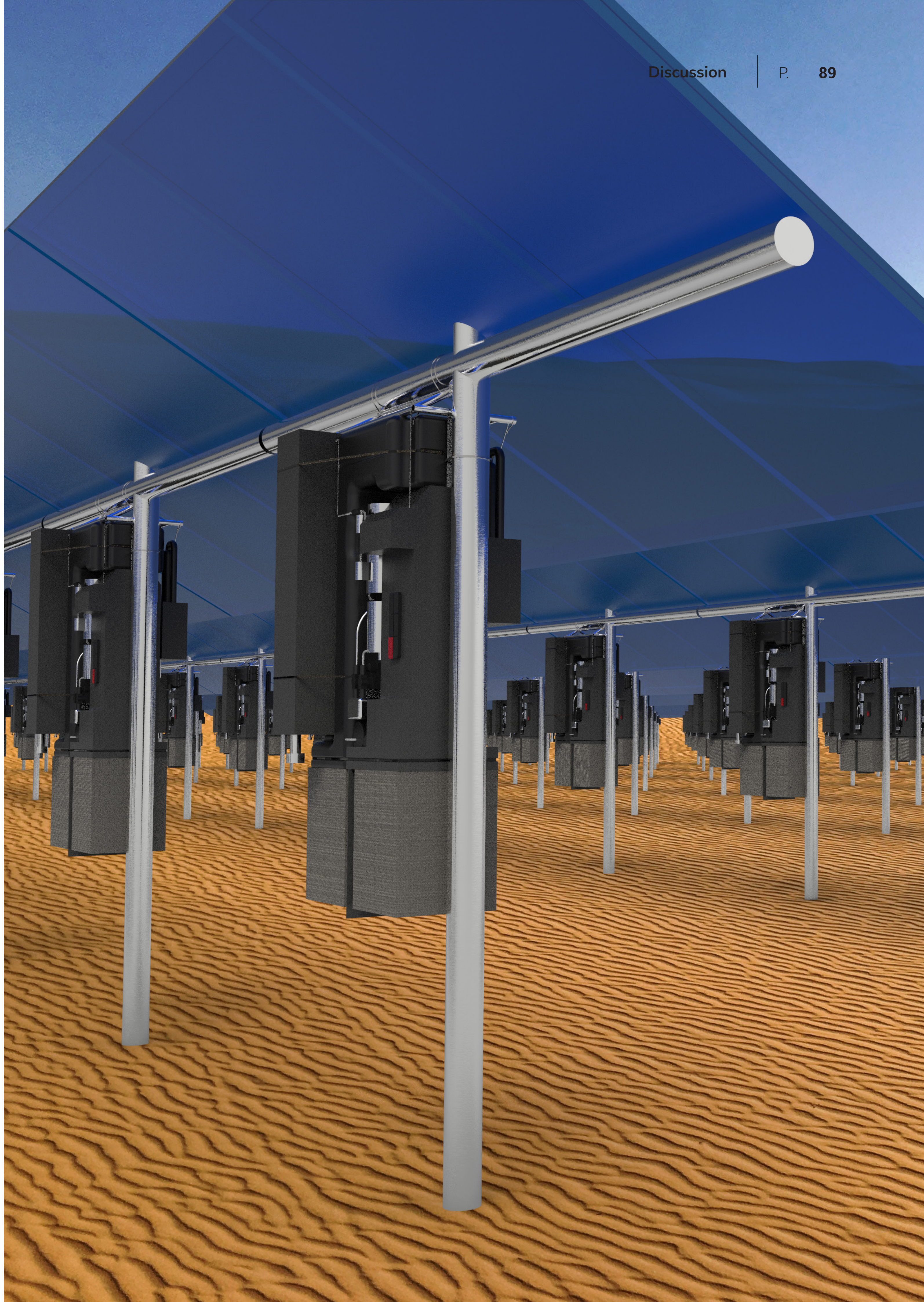
Figure 9.3 Future planning

this project. Lots of technology parts were not designed in full detail and for mass production yet. When the technology parts are designed for mass production, the engineers must know its influence in its broader context. Therefor a step by step design guidelines for engineers has been developed (figure 9.4). The engineers have to start on all the dark blue boxes.

**Goal:** It was essential to guide ZEF towards an embodiment design. Guiding is done by illustrating the design options. To explicate, this guiding an overview of the design options and the main design drivers that influenced their choice has been provided in figure 9.5.

**Stakeholders:** during the project, multiple companies were contacted for advice. Some contact did not result in anything, other contacts, turned into company visits, where numerous insights were obtained. For the next projects, it is advised to use the same contacts. In this way, ZEF can maintain lasting relationships with companies, resulting in fruitful collaborations. The contact information can be found in appendix I.





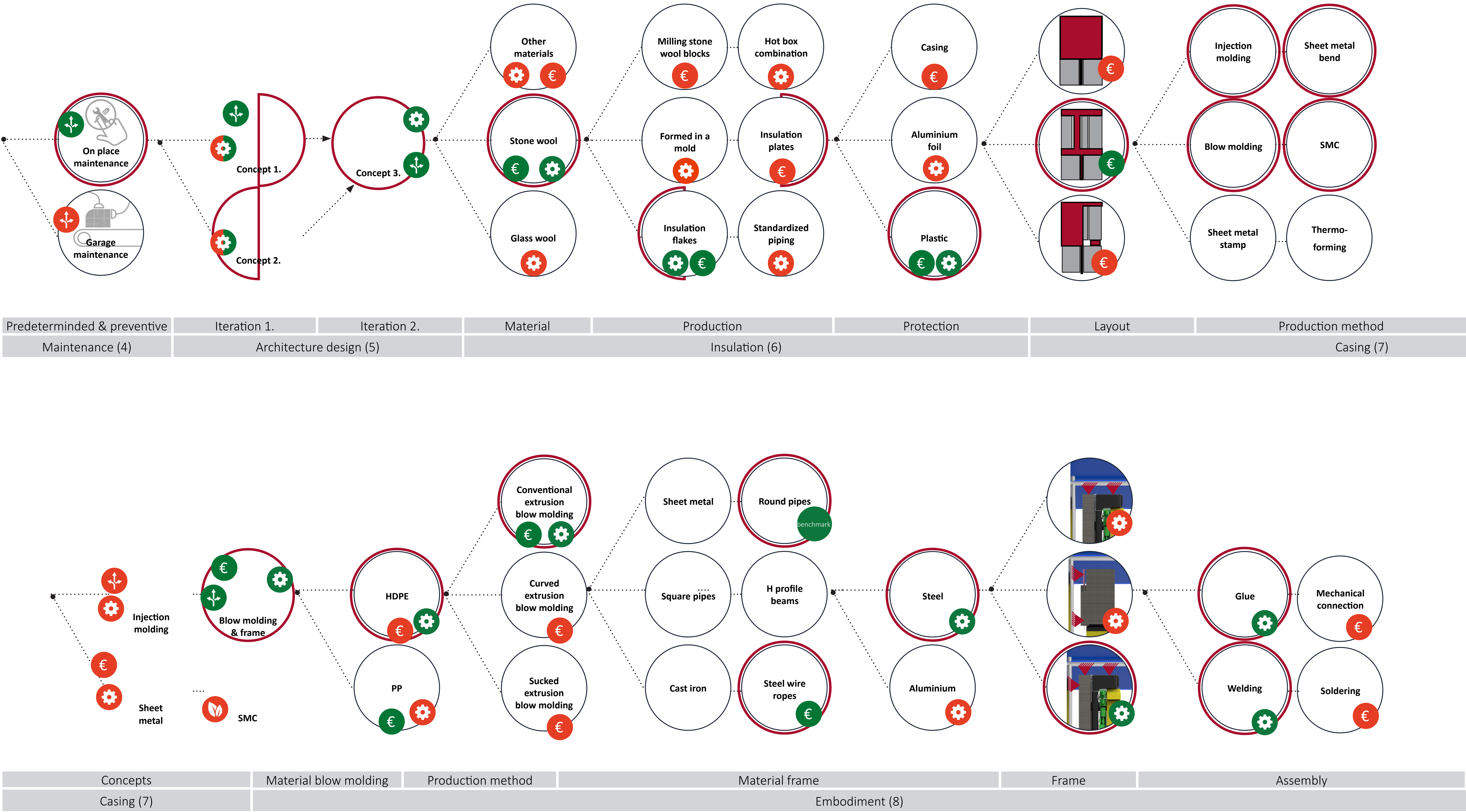



Figure 9.5 Design options and driver

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# Methanol from sunlight and air: A guide towards the embodiment design of the micro plant

Appendix



# A. Exploration

## A.1 Stakeholders

**Methanol dealers:** Methanol dealers want to buy cheap methanol. Methanol dealers are less likely to buy the methanol if it is more expensive than methanol produced by big plants (figure 2.2.3). Methanol dealers might show an increased interest if the methanol can be certified as 'green'.

**Media**: It is assumed that the media will expect a micro plant that looks like it is going to be good for the environment. It should therefore appear different compared to the current oil/methanol production plants. Media can play a role in selling the micro plant, government attitude, and environmental organizations' reaction.

**Research and development (R&D):** The research and development is presently carried out by by students (interns and graduate students), external parties, and the management at ZEF. The research and development is an ongoing process and not finished yet. A visual representation of the micro plant could give students a vision of the end micro plant. R&D provides information about the technology level of the micro plant.

# B. Program of requirements

## B.1 The micro plant

The micro plant should contain all parts described in appendix C. [2.1]

The parts should be connected using 6mm diameter tubes as illustrated in figure A.1. [2.1]

The micro plant should be attached to the PV solar panel rack (it is assumed that this will be a vertical beam). [2.1]

The lifetime of the micro plant should be at least 20 years, taking into account that it gets on average maximal 52h maintenance per micro plant per year, with an acceptable failure rate of 2% over 20 years. [2.1]

The noise created by the micro plant cannot exceed 80 decibel [2.2]

## B.2 Maintenance

When the micro plant stops working a signal should alert a maintenance employee of its malfunctioning. [2.6]

It should be possible to swap (detach the broken micro plant and install a new micro plant) a complete micro plant within 30 minutes with the help of 2 maintenance workers. [2.6]

The maintenance work of the micro plant should be easy to do by a maintenance employee. The parts that require maintenance should be easily accessible and the micro plant should be at a height accessible without extra support. [A1][2.6]

Safety: Maintenance work done by maintenance employees should not involve high risks, parts with high internal pressure should not be easy to disassemble for maintenance employee workers. The maintenance employee should not be stimulated to open other parts of the micro plant other than the parts that need maintenance.[2.2]

The micro plant should have the possibility to be disassembled by trained repair employees for repair and analysis purposes. [2.6]

It should be possible to manual power of the micro plant.
The micro plant should be operatable by maintenance employees, after following a training.

Parts that are hotter than 60 degrees should be indicated or protected, so that



maintenance employees are discouraged or unable to touch those parts(ASTM C1055-03. 2014).

It should be possible to transport a detached micro plant, for repair and analysis purposes.

## B.3 Environment

The micro plant should be able to withstand temperatures of maximum 50 degree Celsius and minus 18 degree Celsius. [2.4]

The micro plant should be able to withstand rainfall and hail of 1 millilitre per minute. [2.4]

The micro plant should be able to withstand the wind that exceeds speeds of 100 km/h. [2.4]

The micro plant should withstand sandstorms. [2.4]

The embodiment of the micro plant should avoid dust from affecting its functionality. [2.4]

The micro plant should be able to coexist with the reptiles, small mammals, birds and insects that live in the desert. Big Mammals are assumed to be avoided with fences. [2.4]

The exact composition of all materials in the micro plant should be documented and if possible indicated in the micro plant for end of life purposes.

## B.4 Production

The micro plant should be produced reliably and economically.

The final embodiment and architecture design should be suitable for the production of micro plants the first 7 years after the realisation of the first farm. [2.5]

The parts of the micro plant should fit a batch size of over 40.000 micro plants. [2.5]

After assembly, before usage in the desert, every micro plant should be safe to use and be able to pass a test in a controlled environment (this might happen with every micro plant or at random). [2.5]

## B.5 Cost

The micro plant should be able to produce methanol for around 150 euro per PV solar panel equivalent.

# E. Architecture design

## E.1 Morphological chart

| | | | | | |
|---|---|---|---|---|---|
| **1a. Architecture design:** subsystems | Subsystems kept together | Mixture of all subsystems | Similar parts like solenoid valves together | | |
| **1b. Architecture design:** maintenance | Maintenance on one side, outside the casing | Maintenance not centralized inside the casing | Dangerous exits on the other side than the side of the maintenance | Maintenance parts centralized inside the casing | Maintenance parts outside the casing, all over the place |
| **1c. Architecture design:** insulation | Insulation parts together | Insulation parts inside the casing | Insulation parts spread | | |
| **1d. Architecture design:** cooling | Cooling parts outside the casing | Cooling parts inside the casing | Cooling parts inside a second layer of casing | Cooling parts inside the air-shaft | Cooling parts on the other side of the maintenance side |
| **1e. Architecture design:** PCB | PCB inside the casing | PCB attached to the absorption column | PCB behind a bracket | PCB in a separate casing outside the normal casing | |
| **1f. Architecture design:** wires | Wires distributed with cabel tray | Wires distributed in the casing | Wires distributed behind a bracket | Wires distributed with tyraps | |
| **1g. Architecture design:** Assembly | Hang parts on a bracket | Stack on a bracket | Stack inside the casing | Hang inside the casing | |
| **2. Insulation** | Vacuum | Loose insulation flakes pressed | PUR foam | Solid insulation pre manufactured | |
| **3. Casing** | Injection molded casing | Metal bended | | | |
| **4. Maintenance** | On side by hand | On side partly with machines | On side fully automated | In a garage partly with machines | In a garage fully automated |

Table E.1 Morphological chart



# E.1 Extra information architecture design 1.

**2. Insulation**
For insulation, there is chosen to have solid insulation. Vacuum insulation is almost impossible because of the piping and cables that create heat leaks. Figure E.2 illustrate where about the insulation will be placed. The insulation is indicated in red. It is assumed that between 5 and 10 cm of insulation thickness is needed around a part. The thickness of the insulation is dependent on the ideal temperature of the part.

**3. Casing**
The casing will be injection molded to have shape freedom and to satisfy large production volumes. Figure E.1 illustrates the casing of the design. This illustration is an indication of the volume of the casing. The light blue parts on the casing are touchpoints for maintenance. The four blue parts on top are entrances for refilling oil, KOH, and Sorbent.

**4. Maintenance**
Figure 4.7 illustrates how maintenance can be done at the place of the micro plant. Individual bottles can be used for refilling. It also shows an outlet at the bottom that can be used for drainage. On the maintenance interface, there are:

Two manual valves.

A button for manual maintenance and a button for Sorbent maintenance. That are colloured in figure 4.7 to illustrate that they are activated.

A blue box that is used as a water vaporizer and oil collector.

The orange lines on the side indicate danger because of the hot temperature of the coolers.

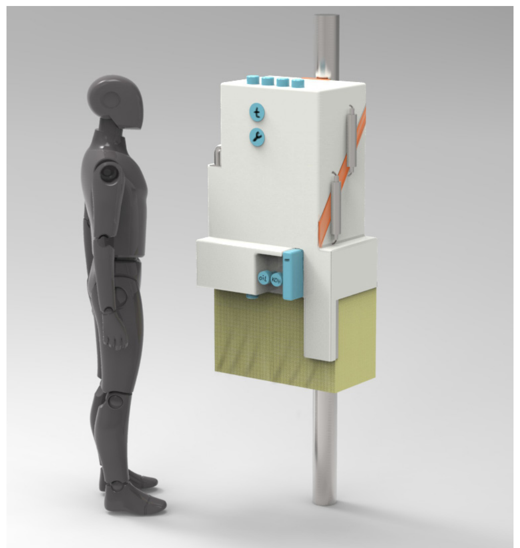

Figure E.1 Casing

Figure E.2 Insulation back

# E.2 Extra information architecture design 2.

**2. Insulation**
The parts that require insulation will be insulated using loose insulation flakes. For this, it is necessary to have a closed casing or a closed casing around the insulation parts. The flakes will be added inside this casing. The advantage is that it is easy to insulate complicated parts with wires and piping.

Figure 4.11 and E.5 illustrate the place of the insulation indicated in red. Parts that require maintenance are placed in the same area.

**3. Casing**
This concept uses an injection molded casing for the same reasons as concept 1. Figure 4.13 illustrates the volume of the casing. It also illustrates that there are no touchpoints for maintenance, and except for a small part of the MS, there are no cooling parts outside the casing.

**4. Maintenance**
Figure 4.14 illustrates how the micro plant can be swapped to do maintenance in a garage. Figure E.3 illustrates an idea for the integration of power cables and methanol piping inside the racks that hold the PV solar panels. This makes it easy to swap micro plants, without detaching the methanol and power input. It also protects the piping and power connections.

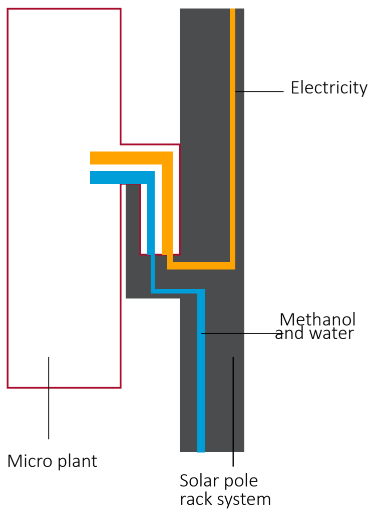

Figure E.3 Micro plant attachment

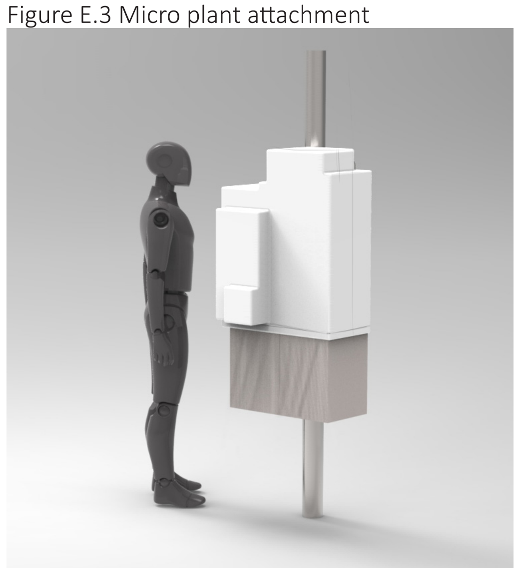
Figure E.4 Casing

Figure E.5 Insulation back



# F. Insulation

## F.1 Insulation materials

Figure fixme gives an overview of the materials selected with the CES database using the following requirements:
- Price per unit volume: max 10.000 euro/m3
- Density max 500 kg/m3
- Max serve temp.: min 250 degree Celsius
- Thermal conductivity max 0.8 W/m Celsius

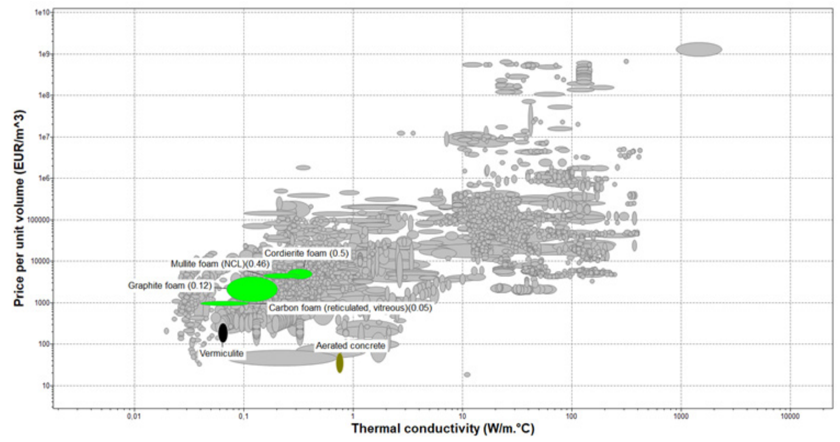


Table Fixme illustrates the materials from the CES database and the materials from the papers that suited the requirements of tempreture range. The materials are ordered at thermal conductivity. The table illustrates that glass and stone wool are better insulaters for a cheaper price than all the other products.

| Material | Thermal conductivity Maximum (W/m K) | Thermal conductivity minimum (W/m K) | Price (Euro/Kg) | Price (Euro/Kg)2 |
|---|---|---|---|---|
| Glass wool | 0,031 | 0,037 | 0,9 | 1,35 |
| Stone wool | 0,033 | 0,04 | 1,1 | 2 |
| Recycled glass fiber | 0,038 | 0,05 | 0,45 | 1,215 |
| Vermiculite | 0,0581 | 0,0704 | 1,71 | 2,06 |
| Expanded vermicultite | 0,062 | 0,1 | 1,71 | 2,06 |
| Carbon foam | 0,04 | 0,11 | 17,8 | 21,3 |
| Graphite foam (0.12) | 0,07 | 0,2 | 15,6 | 23,4 |
| Mullite foam (NCL) (0.46) | 0,15 | 0,317 | 8,88 | 10,7 |
| Cordierite foam (0.5) | 0,25 | 0,417 | 8,12 | 12,6 |
| Aerated concrete | 0,7 | 0,8 | 0,0514 | 0,0685 |

## F.2 Interview InsulationSolutions

They advised not to use Aerogell, because this is too expensive. Using a rigid foam for the AEC and the DAC insulation will be to risk full because the thermal properties are not stable over time. A different solution is the use of insulation matrasses. However, this is only used for applications where the insulation material needs assembly and disassembly multiple times during the micro plant's lifetime. Because this is not the case with the micro plant and because this solution is expensive, it will not be used. They also advise using an elastomer foam material named Armacell for the AEC and DAC insulation that can handle temperatures up to 150oC. The insulation properties of Armaceell are, however, not as good as stone wool or glass wool. There is no evident benefit of using two different insulation materials.

## F.3 Manufacturing methods stone wool insulation

different manufacturing methods for stone wool insulation.

The information is obtained from interviews with InsulationSolution and Rockwool. The different options are:

Standardized piping insulation: Rockwool produces standardized piping solutions in different sizes and thicknesses. 2 layers of piping insulation can be used to create a more significant thickness. The insulation is formed out of 2 pipe shells placed on top of each other. Piping can be delivered with an aluminum layer on top of the insulation or a gauze blanket. The gauze blanket can be used to close the insulation. The aluminum layer can prevent radiation of heat. There are prefabricated bends in the assortment, to use for the MS. Flange caps can be used to close the pipes; wool is on the inside of an aluminum flange cap. It is a benefit that the insulation can be made from standardized piping. It is a disadvantage that the assembly of the piping is time-intensive. Wires and piping connections are harder to integrate into the insulation using standardized piping with a more significant risk for heat leaks.

Milling of stone wool blocks: Stone wool can be milled, so it exactly fits the shape of the insulation parts. It is a disadvantage that milling stone wool blocks for 100.000 micro plants is a time-intensive process.

Insulation flakes: Flakes can be used to fill a closed cavity with flakes. This method is often used for complicated shapes. The insulation value is slightly lower than blocks, because of the random orientation of the fibers. This difference is, however, neglectable considering the benefit of having a perfect fit with the parts. A disadvantage is a need for a closed casing or confinement around the insulation parts.

Stonewool formed in a mold: It would be perfect if the stone wool can be produced using a mold, so it does not need secondary processes to fit the design. It is unclear if this method is possible. Rockwool and insulation solutions do not yet offer this possibility to their customers.



One of the above options in combination with a hot box: When all parts need to be the same temperature, an insulating casing that goes around, all parts can be used. This is similar to a refrigerator; instead of cooling every product individually, they are placed in an insulated chamber with one temperature. However, the parts require different temperatures. Nevertheless, it would be possible to insulate the parts that need to be hotter than 70 oC and not insulate the parts that only need to be 70 degrees, so it is a hybrid solution.

# G. Casing

## G.1 Benchmark

There is one Dutch company, MasterVolt, that produces invertors. They mainly produce invertors for the maritime sector. Their casing was made from sheet metal because:
They have small production volumes.
It is easy to create a new version of the design with sheet metal.
The metal can also function as a heat sink.
Plastic is less fire-resistant; for them, this is a reason to use metal.

Bottlenecks in the design of the inverter are:
The connectors to the solar panels.
Thermal management
Inside the sheet metal, they have a sheet metal bracket to keep al the components together.

An interpretation of rules are listed that could also be relevant for the design of the micro plant:
The micro plant needs to be grounded to protect from electrical shock.
It should not be possible to get an electrical shock by touching the micro plant.
Accessible parts that have the function to get hot can not exceed temperatures of 100 oC
The part of the casing that gets into contact with the mounting surface can not exceed temperatures of 90 oC
Push buttons an actuators of emergency stop devices and indicators of warning or danger should be colored red.
The IEC also gives much information on how to test if a product applies to the rules; in a later phase of the design, it might be necessary to dive deeper into this topic. A lot of these tests involve testing what happens if one function of the design fails. For example, if the air duct is blocked, what will happen, and is this dangerous? The IEC also gives information on how to mark certain parts, for example, parts that get hot or can be mounted. This should be considered in a later stage of the design process.



## G.2 Pro and con's of the casing concepts

### Concept 1.

**Pro:**

- Suitable for large production volumes
- Airshaft is not a load bearing part, therefor a cheap and virgin plastic can be used. The virgin plastic can be recycled after the lifetime of the micro plant.
- Shrinkage an the expansion of plastic, due to temperature differences in the dessert are not a risk because the airshaft only has one function.
- he metal frame allows flexibility in the design of the assembly of the micro plant.
- The metal of the metal frame can be recycled after the lifetime of the plant.
- If the airshaft needs to change after running one farm of 10.000 pieces the investments for a new mould are bearable.
- Blow moulding is commonly used for parts of these sizes.

**Con:**

- It is a hybrid construction that requires secondary processes and assembly of the airshaft to the metal frame.
- Blow moulded parts have limited from freedom.
- Blow moulding will generate waste material in the production process.
- Assumed is that the plastic prices will rise the coming years.
- Plastic will melt under high temperatures.

### Concept 2.

**Pro:**

- All functionalities can be integrated in two parts.
- Less need for secondary processes.

**Con:**

- Only virgin plastic material can be used.
- Plastic deforms under the forces applied to the part.
- Plastic deforms and degrades under the influence of temperature. This is a problem when the part is also the structural frame of the thing.
- High investment costs
- High costs to change the design.
- The parts that are needed are large parts. The plastic industry is for 95% specialised in the production of small parts. It is possible to make plastic parts of this size, but it is not common and it comes with it challenges

### Concept 3.

**Pro:**

- SMC has a better stiffness than plastic
- SMC is more resistant to high temperatures.
- SMC has enough form freedom to integrate all functionalities into one part.

**Con:**

- High investment costs.
- SMC is not recyclable.

### Concept 4.

**Pro:**

- It is easy to iterate with sheet metal and create new versions of the product.
- No investment costs.
- Sheet metal can be bend in a way that it is stiff.
- The metal can not melt and has a long lifetime.
- Metal can be recycled after the lifetime.

**Con:**

- Need for secondary processes to make a leak tight airshaft and assemble all the sheet metal parts.
- Not easy to upscale for large production volumes.



# H. Casing

## H.1 Design guidelines blow molding

1. The ideal shape of a blow mold part is the shape of a sphere. In the design, it is best to approach this shape as much as possible.
2. If the end product is larger than the parison's diameter, the material will stretch, and the wall thickness will decrease. This decrease in material happens very rapidly. When creating an expansion on the side, the ratio of 1 to 2 should be followed. It is essential for the blow mold process that this extrusion does not create a leak. However, minimal wall thickness can be done on purpose when the material needs to be removed for the assembly of other parts.
3. The product should be designed in a way that the diameter of the parison can be as small as possible. A large parison diameter is heavy, will stretch and need to be held by the extrusion head. A larger parison also requires a bigger machine and a more significant mold resulting in higher mold costs and higher production costs.
4. In extrusion, blow molding only to 5 to 7 Barr is used to blow the product. Therefore it is possible to use soft material for the mold, an aluminum mold. If an undercut is in the design, there is a need for a slider. However, because fo the softness of the aluminum, the slider will eat the mold, therefore it is best to design the part without undercuts. One exception can be made; the material will shrink about 2% after blowing. This shrinkage allows for small undercuts.
5. The weld seam does not necessarily need to be in the middle of the product.
6. There can only be one cavity, but this cavity can consist of multiple product parts.
7. The flap could not  be cutted at the product edge but at a distance to give it a function.

DESIGN FOR our future

TU Delft

# IDE Master Graduation

## Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

**USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT**

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

## STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name

initials given name

student number

street & no.

zipcode & city

country

phone

email

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD ◯ Dfl ◯ SPD

2nd non-IDE master:

individual programme: (give date of approval)

honours programme: ◯ Honours Programme Master

specialisation / annotation: ◯ Medisign

★ Tech. in Sustainable Design

◯ Entrepeneurship

## SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair dept. / section: SDE / PAD

** mentor dept. / section: SDE/ Dfs

2nd mentor

organisation: ZEF (Zero Emission Fuels)

city: Delft country: The Netherlands

comments (optional)

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

**Procedural Checks** - IDE Master Graduation

TU Delft

## APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair Prof. ir. Oberdorf, J.E. date 3 - 3 - 2020 signature

## CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair. The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _____ EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date - - signature _____

## FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **. Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name _____ date - - signature _____

# Product design of a circulair methanol plant

project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 10 - 02 - 2020 01 - 08 - 2020 end date

## INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

The need for new sustainable sources of fuel:
The world is in need of new sustainable energy alternatives. Because first of all burning fossil fuels releases CO2 in the air that has been stored inside the earth for years. Burning these fuels is resulting in a growing concentration of CO2 in the atmosphere, this is seen as the cause for climate change. Secondly fossil fuels become more scarce and will eventually run out. Only 30% of energy used is electric, so changing to electricity based green energy, like solar and wind power, will not fulfill the need for sustainable energy alternatives. That is why a new sustainable fuel alternative is needed.

The choice of methanol:
Three most used sources of energy are: oil, coal and gas. Of these sources only methanol and hydrogen are renewable. This project has it focus on methanol firstly, because methanol is the simplest alcohol with the lowest carbon content and the highest hydrogen content. Secondly, because methanol is a basic building block of hundreds of essential commodities and can be used as fuel. Every year 70 millions tonnes of methanol are soled.

Current production of methanol:
Methanol is currently produced in large chemical plants, by utilizing gas or coal. It takes years and large investment to develop and built such a plant.

The company:
ZEF (Zero Emission Fuels) is a start-up founded in July 2017 that aims to provide a sustainable way of producing methanol. They are developing a methanol producing product that can produce methanol form solar energy and air. By making a product suitable for mass production and than placing it in the desert, attached to a solar-panel, they can create a relevant and competitive product.

Simplified working principle of the product:
First the product collects CO2 and H2O from the air. Secondly it brings the CO2 an The H2O to a pressure of 50 bar. The next step is to turn the H20 into H2 and 02. Finally this dissolves into water where it reacts with the CO2 to turn into CH3OH (methanol). The energy needed for these processes is collected with a solar panel.

Current challenges:
In order for the product to compete with the current methanol prices the product should cost around 150 euro per Solar Panel equivalent and needs to produce methanol for a minimum of 20 years with minimum maintenance needed. It is still a challenge to target this cost price. All the different subsystems are developed independently. Integrating these elements in the optimal way, in which they can withstand the extreme weather conditions of the desert, and are still cheap is a major challenge. It is also still a question where the products will be produced, who will assemble them and who will be responsible for installing them in the desert.

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introduction (continued): space for images

image / figure 1: Methanol farm: a render illustrating how a methanol farm might look like in the future

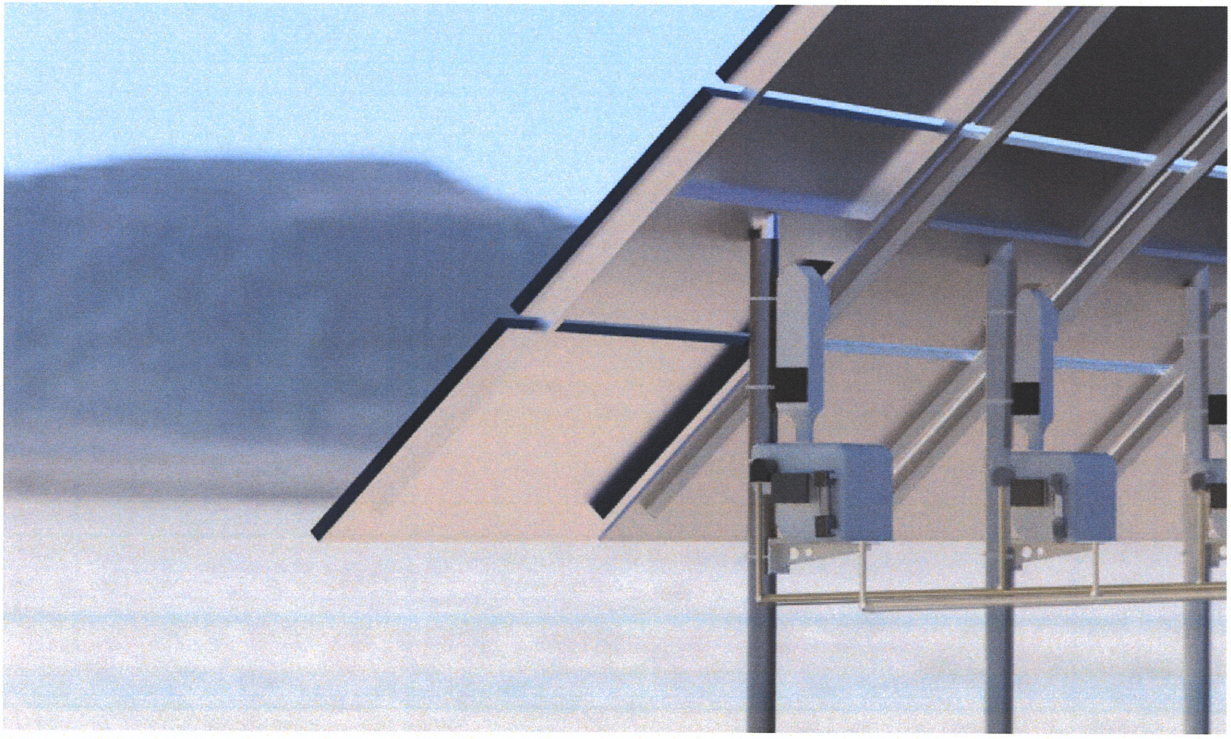


image / figure 2: A close up of how the product might look like in the future

## PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

All subsystems are developed in the last 3 years to prove yield, efficiency and manufacturing. Now all these different subsystems need to be integrated into one product. The current research into the integration of the subsystems is not up to date anymore since the subsystems have been changed. The research only looks into the architecture design of the system on a surface level. Research into isolation, distributing of wires, materials and production methods for embodiment and assembly still has to be done.
Furthermore the product is going closer to a state where it needs to attract investors and prepare itself for mass production. That is why there is a need to create one coherent product architecture that integrates the different subsystems more detailed.

The current subsystems are:
- The compressor
- The direct air capture
- The alkaline electrolyser cell
-The methanol synthesis system

All the subsystems need to be put together. The proportions of the different subsystems need to make sense together. To produce methanol that can compete with the current methanol prices the product should be able to produce methanol at a production price of 350 euro/ton. Therefor the costs of the isolation, the materials, the production method have to be taken into account.

Not only cost but also the environmental impact of different design decisions have to be researched.

## ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... . In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

The target of this project is a coherent product architecture for the methanol plant. This architecture design will merge research about isolation, human interaction, production, assembly and other into one coherent design. The result is a guidance for ZEF that allows future teams to understand the product and to proceed with the next stage of attracting investors and realizing the product.

The architecture of the product arranges all the functional elements of the product in the most optimal way. The product architecture will serve as a source material where all functional elements are described. It will give guidelines on how to turn functional elements into physical components.

To achieve this result I first need a backbone for the design. First, the problem will be described. Secondly, a detailed program of requirements will be defined. The different stakeholders will be researched to properly address their concerns in the design.

To merge all the research into one coherent whole, a concept design for full integration is required. This will include iterating and validating design decisions.

The result of the architecture design should create value for all stakeholders, It should also give insight and guidelines about important design decisions for the future. The research about embodiment design should give a starting point and guidance for ZEF for future design iterations.

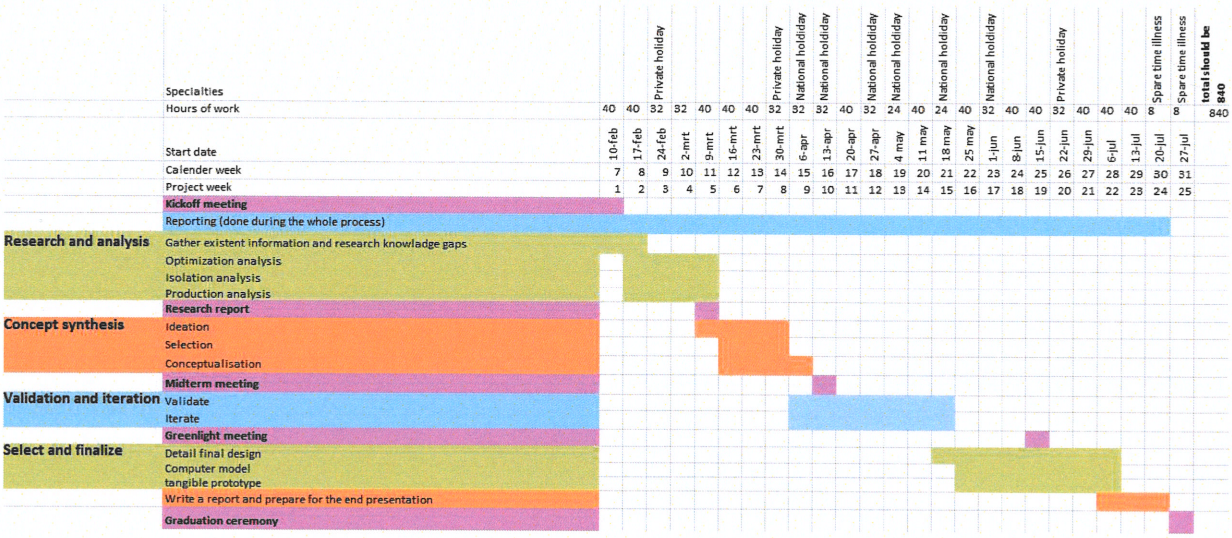
With a coherent product architecture and embodiment, as a result, I aim to have a valuable output for ZEF and other stakeholders.

## PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 10 - 2 - 2020

1 - 8 - 2020 end date




During this project, I want to follow the following steps using a double diamond method. I will diverge during the discover phase, converge during the product definition. Then I will diverge again during the development of the product and finalize the product architecture in the deliver phase with converging methods.

Research and analysis (discover): I will get familiar with the current state of the project, using a functional analysis. Secondly, the design requirements will be analyzed to integrate the different subsystems. I will analyze the concerns of the different stakeholders. SMART requirements will be formulated.

Concept synthesis (define): I will brainstorm ideas to create a coherent product architecture. I will use the program of requirements to converge the number of ideas and turn some of the ideas into concepts. From the concepts, one will be choosen using a converging method like the harris profile.

Validation and iteration (develop): The concept needs to be validated by different stakeholders. Throughout this process, I will come across challenges that require the concept to change. I will iterate on the concept until it is perfect. To check if I took everything into account I can use checklists for concept generation.

Select and finalize (deliver): In the last stage, I will have to details the last bits of the design and turn the concept into a tangible result using prototyping.

Documentation will be done throughout the whole project.

## MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... . Stick to no more than five ambitions.

Sustainability aspect
During my master program, I have followed the annotation: 'Technology for Sustainable Development'. I chose this annotation because I think as a designer I have a responsibility. I can choose what kind of products I want to design and how I want to design them. Putting my effort in the design of this product allows me to apply the knowledge, passion and energy I have for sustainable products. I want to change the world into something better. I want to make a living out this when I graduate. I believe this project will challenge me, to do even better. I also believe this project will open up relevant career opportunities.

Technical aspect
If you would put industrial design engineering on a scale from conceptual to highly technical, then this project would be on the technical end of the scale. This is great because this is also where my interest lie. During the bachelor, there are lots of classes about the engineering part of the design, in the master, there are not that many classes about that and the focus is more on putting this knowledge into practice throughout design projects. I think that this project will take me one step further and allows me to deeper understand what it takes to develop a product, but it will also widen and deepen my engineering skills with the optimization part, the finalizing of the design where I will use Solid Works to create a computer model. It will give me the opportunity to learn about production and assembly techniques in a richer way than learning from a book.

Management aspect
This project is a complex project with different stakeholders (TU Delft, ZEF, Potential production partners, companies that ZEF is collaborating with and me). Within ZEF there is a big group of interns that change over the year and the different subsystems are designed by different people. My task will be to put all of this together in one coherent and feasible product. This does not only require hard skills, like math and 3D-modelling. But this also require social soft skills. During my studies, I have worked in many different project groups where I could learn these soft skills. But I was also part of several committees where I had different functions from chairwomen till secretary. I did a minor education where I needed the soft skills to control 30 schoolchildren and I did an internship In Nepal where I was the only one with a design background. All these experiences have learned me to not only manage technology but to also manage people in complex environments and to add structure in chaotic situations. Within this project, I hope to take my soft skills to the next level because of the complexity of the project and my responsibility in this project.

Design aspect
Putting something abstract and fuzzy into something feasible and tactile, and to create something new and relevant out of nothing, that is amazing. Engineering is abstract to the public, that is where is design comes in. If we look at a product and a designer has thought about ways we can understand its functionality, it will be used in the right way, it will be relevant for people of this generation and not compromising the ability for further generations to fullfill their own needs, then we can say it is a good design. But it was only possible because a designer integrated all this engineering and created it into a product. I would love to do that with this project.

## FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.