DESIGN OF A USER FRIENDLY, SAFE AND EFFICIENT BIOMASS GASIFIER FOR VIETNAMESE HOUSEHOLDS

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EXECUTIVE SUMMARY

Context

This master thesis describes the process behind the development of a mass producible micro gasification cookstove. The context in which this project was executed in was Vietnam. Starting with an extensive analysis on Vietnamese cooking traditions, different cookstoves in the market and gasifiers that are already being produced worldwide. It is determined what requirements should be considered depending on primary user needs. For Vietnam the segment most in need of a gasifier cookstove are large ethnic groups in the North. These groups are difficult and expensive to reach as they live in inaccessible areas and are even decreasing in numbers every day. Therefore, this is not the most interesting target market economic wise, but it is a social problem nonetheless. The true challenge is to reach the highly demanding 9 million rural households and farmers that are progressing towards new living standards. These consumers need cookstoves to be functional, affordable, and aspirational products.

Technologies

Gasification is the main technology of focus during this project. Research has been executed towards the optimization of mixing generated gas by means of gasification, with additional secondary air inside a special burner to reach optimal combustion conditions.

Situation

There are many attempts to make a commercially successful gasifier stove by companies all over the world. Some did manage to sell their product to the market, like the Oorja pellet stove from first energy, which sold over 400 000 units between 2006 and 2010 in the Indian market. This is a small success but the developed gasifiers are still lacking in many areas.

Project achievements

This project started off with a goal, to bring a promising lab prototype towards a product that is ready for mass production. In addition, an attempt would be made to set up a production line and start the implementation of the improved gasifier design into the market. Soon after the start of the project it became clear that, this step had to be delayed as certain aspects of the lab prototype still had to be improved. Main components like the burner had to be optimized, before it was near a point where production could be started. Which brings us to the following question, what has been achieved within this project?

The biggest step forward are the improvements made to the design of the burner. Experiments showed that the new burner design improved the mixing of the primary and secondary air. This in addition to optimization of the gas velocity made the flame burn on top of the burner ports. This improved the efficiency, as well as the product lifespan. Comparing with the old prototype of the gasifier where, the flame was burning inside. This caused the thermal energy from the flame to heat up the metal parts and destroy them. The new design converts more of the thermal energy to the pot rather than wasting it on heating the gasifier. Research towards mass production possibilities in Vietnam and multiple cost analysis have been made to make future cost estimations much more realistic.

Future steps

The project has made a big step towards the development of a commercialized product. There are still some improvements needed to make this product successful. Based on the market analysis it can be concluded that not only the design of a well-functioning product is key to the success of an improved stove. Other factors like distribution of the product and the fuel need to be implemented as well.

PREFACE

For this project I worked in Vietnam for a little less than three months. During this time, I was received by CCS, the Center for Creativity and Sustainability, located in Hanoi. Even though it was not my first time abroad, this was a real unique experience for me. This report is the result of my graduation project concluding my master Integrated Product Design at Delft University of Technology. I want to thank everyone that supported me during this journey.

Pascal Franken, 2016

TERMINOLOGY

Advanced cookstove	Stove that can achieve high levels of performance
Air equivalence ratio	Ratio of added air to the fuel, compared to the amount that is needed for full combustion
Beehive coal	Usually round shaped coal briquette with penetrated holes that makes it look like a beehive
Biochar	Char that is left over after the gasification process of biomass fuels
Blow back	The movement of the flame to the inside of the burner along the incoming stream of syngas
Blow off	The separation of a flame from the burner port resulting in extinction
Burner	A part of the gasifier that improves the stability of the flame and can improve the thermal efficiency
Burner port	A hole in the burner through which the gas is directed
Crossdraft	Type of gasification in which the created gas flows horizontally, while fuel is added vertically
Downdraft	Type of gasification in which the stream of gas flows downward and the fuel is lit at the bottom
Flame lift	The separation of a flame from burner ports, whilst continuing to burn with some distance from the port
Flame speed	The rate of linear propagation of a flame through a gas-air mixture
Gasification	The process that converts organic or fossil based carbonaceous materials into carbon monoxide, hydrogen and carbon dioxide
Gasifier	A device that controls the gasification process, which allows users to cook in a safe and efficient way compared to regular combustion
Grate	Frame of metal bars or perforated sheet metal to support the fuel in the reactor
Improved cookstove	A term used for stoves that have a cleaner combustion compared to traditional ways of cooking
Inverted downdraft	Type of gasification that is also known as Top-Lit updraft. The stream of gas flows upward where the fuel is lit at the top
Light back	The transfer of combustion from burner port to a point upstream in the gas/ air flow into the mixing tube and usually to the injector/ orifice
Natural draft	Natural draft is from the natural tendency for hot gases to rise in relation to the surrounding gases

Orifice	Opening or nozzle through which the gas is injected into the throat to obtain premixing
Pellet fuel	These are biofuels made from compressed organic matter or biomass
Pot support	Fixed or detachable support for a pot in order to keep the pot at an adequate distance from the flame
Primary air	The air that is added directly to the fuel inside the gasification zone
Reactor	An apparatus or structure in which fissile material can be made to undergo a controlled, self-sustaining reaction with the consequent release of energy
Rice husk	The hard protective coverings of the rice grains. Considered a waste product of the rice production
Secondary air	Additional air that is added to the gas before it is injected into the burner
Semi gasification	Process in which gas is not completely separated from the combustion zone, so gas is being mixed with incomplete combustion resulting in lower efficiency
Stoichiometric air ratio	Ratio of air to fuel to obtain complete combustion
Stove	Cooking device that provides heat and convenience for cooking operations
Syngas	Mixture of different gases that is being created as the product of the gasification process
Tertiary air	The environmental air that is added to the flame/ combustion outside the burner
Top-Lit updraft	Type of gasification that is also known as inverted downdraft. The stream of gas flows upward where the fuel is lit at the top
Throat	Tube in which the gas is mixed with secondary air before it enters the burner
Updraft	Type of gasification in which the stream of gas flows upward and the fuel is lit at the bottom

Abbreviations

TLUD	Top-Lit Updraft
IDE	Industrial Design Engineering
FA	Fan assisted
WHO	World Health Organization
SNV	Stichting Nederlandse Vrijwilligers (Netherlands Development Organization)
CCS	Center for Creativity and Sustainability
VND	Vietnamese Dong (currency) in this report 1,- USD is 22.300,- VND
USD	United States dollar (currency)
BoP	Base of the Pyramid
ICS	Improved Cookstove

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1 INTRODUCTION

1.1 INTRODUCTION

This chapter will give an introduction to the project and is divided into five paragraphs. The second paragraph (1.2) illustrates the problems regarding indoor air pollution and how a micro-gasifier cookstove can provide a solution.

The third paragraph (1.3) introduces the formulated assignment as it was presented by the company. In the next two chapters it becomes clear that in order to fulfill this assignment additional research needs to be executed.

The fourth paragraph (1.4) gives a short description of the company and explains their involvement with gasification. Three of their gasifier prototypes will be presented here, two from previous graduate students at IDE and their latest gasifier prototype. The other gasifiers are described as a time line in the appendix.

The fifth paragraph (1.5) presents the approach to this project. Here, the methodology, the project goals and the project steps will be presented.

1.2 INDOOR AIR POLLUTION

A global silent killer in the kitchen

Households all over the world, especially in developing countries, still rely on solid fuels (both biomass and fossil fuels) for cooking. When used in a traditional manner, high concentrations of harmful emissions can be produced. For many of these users cooking is done inside, in spaces that are not well ventilated. This is known to be the cause of death for nearly 4,3 million people each year. (Ipe, 2014)

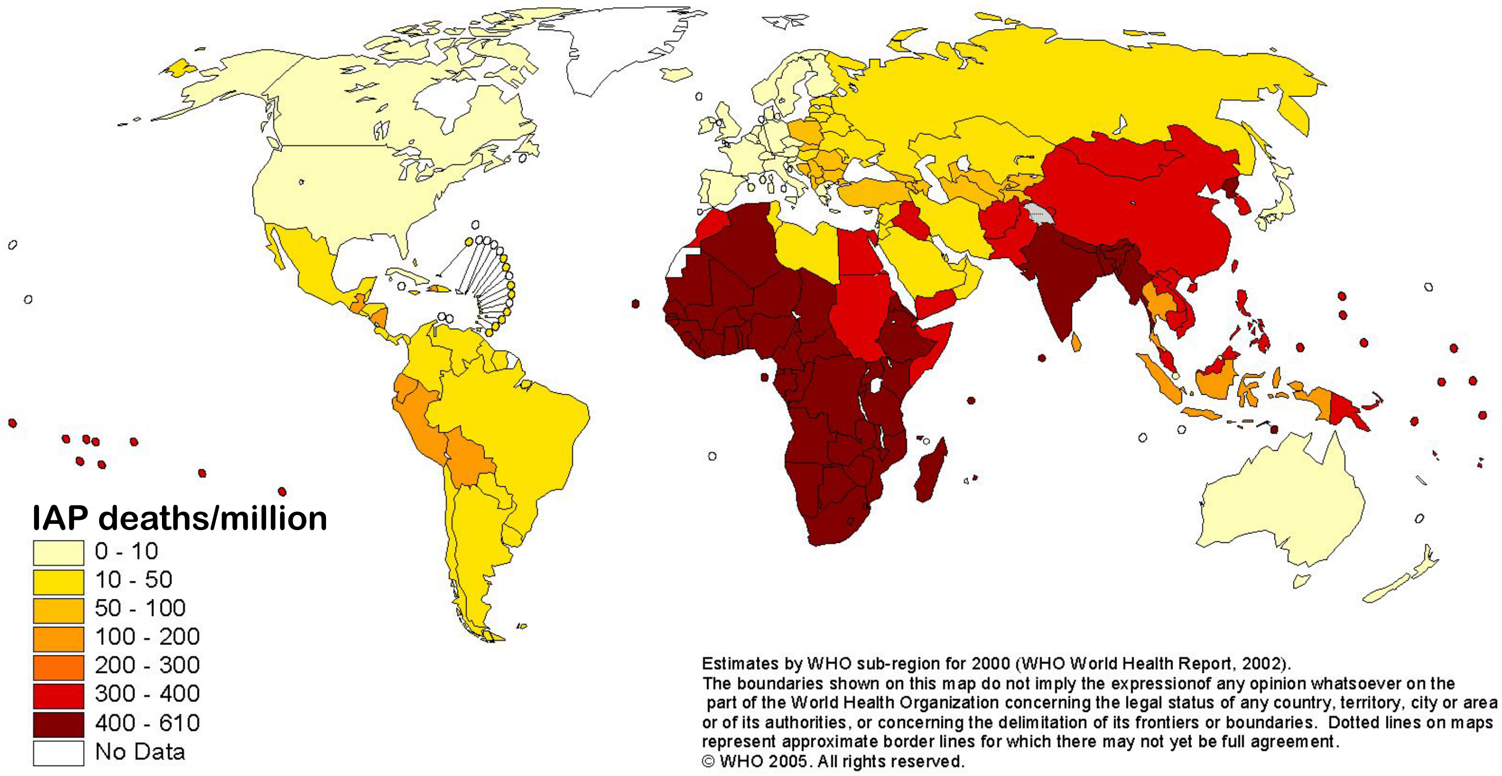


Image 1.2.1: WHO estimates on deaths/ million caused by the use of solid biomass fuels (Who.int, 2002)

1.2.1 Dangers of indoor air pollution

For many decades the use of biomass as a fuel for cooking was considered a transitional problem. This based on the assumption that societies would eventually move up the energy ladder as a result of increased purchasing power and overall economic development. However, people in developing countries, who are often poor, do not have access to modern cooking equipment or are not able to afford them (Ipe, 2014).

The World Health Organization (WHO) has set up standards and guidelines for indoor air quality describing the maximum allowed quantities of toxic gases for fuel combustion (paragraph 1.1.4 WHO guidelines). People in these environments exceed these values by far with their traditional cooking methods. This illustrates the importance of having clean air in and around your living space for a healthy life. A clean cookstove such as a micro-gasification cookstove can help solve part of this problem.

1.2.2 PM2.5

The two main toxic products from incomplete combustion for health are CO and PM2.5. (Who.int, 2004) Particulate matter, or PM, is the term for particles found in the air, including dust, dirt, soot, smoke, and liquid droplets. The PM2.5, applies to fine particles of 2.5 microns or less in diameter. These are considered to pose a high risk for the health when concentrations are high. Due to their size, these fine particles can penetrate deeply into the lungs. Image 1.2.2 on the right illustrates the size of these particles. ("Particulate Matter", 2016)

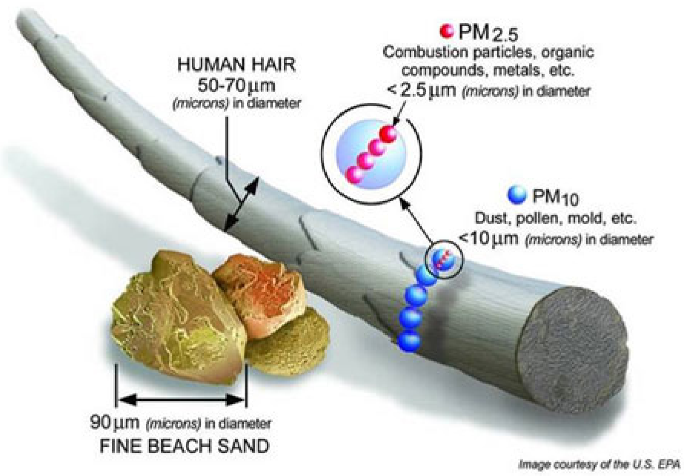


Image 1.2.2: relative size of PM2.5 compared to a human hair and a grain of sand

The health effects of PM are well known, they are due to exposure over both the short term (hours, days) and long term (months, years). These effects include:

- Short term exposure can trigger asthma attacks
- Respiratory and cardiovascular morbidity
- Mortality from cardiovascular and respiratory diseases and from lung cancer

1.2.3 CO

Carbon monoxide (CO) is also a product of incomplete combustion. CO is known as a silent killer, as the gas itself is color- and odorless it will not be detected by people until it might be too late. The real danger of CO is that it has a higher affinity to hemoglobin (red blood cells that transport oxygen through the body) as compared to oxygen. Direct effects of high concentration CO include:

- Neuropsychiatric damage (seizures, coma)
- Mortality from oxygen deficiency

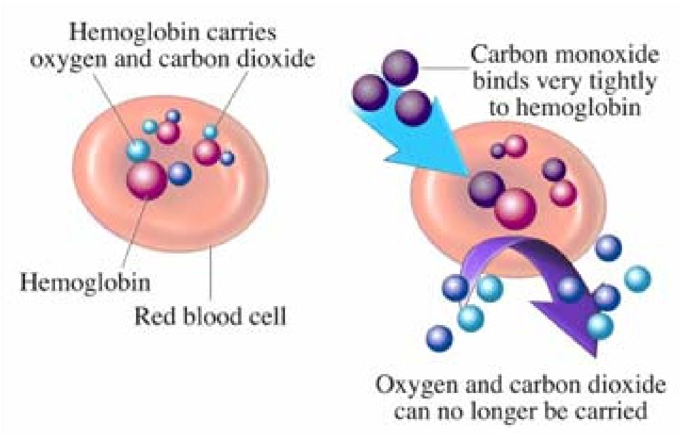


Image 1.2.3: Effect of CO on the human body

1.2.4 WHO guidelines

The emission rates that are required to meet WHO (annual average) air quality guidelines for PM2.5 and the (24-hour average) air quality for CO are listed in the table on the right. (Who.int, n.d.)

The results presented in this table are based on 4 hours of cooking in a kitchen volume of 30 m3. This is assumed to be representative conditions in low- and middle-income countries. These guidelines do not protect against short term spikes of higher exposure values. For example, when a fire is tarted in a biomass cookstove the flame will have a less clean combustion as the reaction temperature is not high enough or the moisture within the fuel is not evaporated yet. Wet biomass fuels are therefore even more harmful.

Recommendation	Emission rate targets	
Emission rates from household fuel combustion should not exceed the following emission rate targets (ERTs) for PM2.5 and CO.	PM2.5 (unventi-lated)	0.23 (mg/min)
	PM2.5 (vented)	0.80 (mg/min)
	CO (unventilated)	0.16 (g/min)
	CO (vented)	0.59 (g/min)

Table 1.2.1: WHO guidelines for indoor fuel combustion PM2.5 and CO

1.2.5 The solution

Gasification of biomass for cooking purposes shows to be a promising solution for several health and environmental issues that occur with traditional methods of cooking. The gasification of the biomass produces a much higher thermal efficiency than the still popular, but very toxic, coal briquettes, three stone fire and other traditional ways of cooking that rely on solid biomass fuels. These methods often produce high concentration gases of incomplete combustion. It is not strange that for this reason, gasification has already been explored widely by many different parties. The main benefits of a biomass gasifier cookstove are summarized in table 1.2.2 on the right. Even though there are some good products and prototypes available, they did not prove to be successful in the market. Some of the reasons for this will be elaborated in the next paragraph.

Virtually no smoke (or at least a lot less than open fires)	
Less toxic emissions which should result in fewer deaths and related diseases	
Cleaner pots and pans, as less black carbon is produced	
Reduction in fuel use, fuel is burned at higher efficiency and more complete combustion	
Reduction in fuel cost, less fuel is needed to generate the same amount of thermal energy	
Faster cooking times, higher temperatures are reached	

Table 1.2.2: Main benefits of using clean cookstoves

1.2.6 Why are many improved stoves not successful in the market?

It seems like a simple task, developing a cookstove that can be produced using modern mass production techniques and fits the user context. One of the problems is that people can be conservative when it comes to changing their cooking habits and traditions. It is safe for people to stick with what they know. However swapping their current stove or fire for a new product such as a micro-gasification cookstove is only part of this complex problem. As will be explained later in more depth, fuel type and availability plays an important role in the success of using such cooking devices. A good example is the Oorja pellet stove (“First Energy - Oorja » a real alternative”, 2015), they supply both the stove and some fuel to their consumers. But based on observations in Vietnam pellets are not widely available for the consumer. This would be the same as buying a car with a full tank of gas, you will enjoy it for the first couple of runs but when the tank is empty and no fuel is available the car becomes useless. The same principle goes for the an improved cookstove.

Even with all of the benefits that are usually advertised with newly developed stoves, it does not appear to be enough. According to a paper on policy implication on improved cookstove programs (Vahlne & Ahlgren, 2014) a lot of stove programs failed because they tended to focus only on rural areas instead of also including the urban area. The issue here is that consumers in the rural area could often save only time and biomass consumption, but no money. Reason for this is that fuel is often freely available for them.

Investigating primary user needs should help improving the adoption rates and keep people from their current cooking methods as presented in image 1.2.4 on the right. Recent attention from the media and political agenda's do show that effort is being made, but that there is also a lot of work to be done. A recent article in a Dutch news paper (NRC next) covers a story about this subject and is documented in appendix B.1.

Image 1.2.4: Cooking inside on an open fire using a iron bar pot support

1.3 THE ASSIGNMENT

This graduation project starts with tackling the problem of indoor air pollution and providing a safer alternative for people who are still using unhealthy traditional cooking methods. This is a big challenge for just six months, but there is already a lot of work and research done in this field. The company for which this project will be executed has made various working prototypes and has several years of experience working with gasification.

The assignment is formulated as:

"Bridging the gap between a lab prototype gasification cookstove and a commercialized product. By fulfilling and implementing the primary user needs into a final design."

Image 1.3.1: Photo CCS signs outside on the streets in Hanoi, Vietnam

1.4 THE COMPANY: CCS

The project will be in collaboration with CCS, Centre for Creativity and Sustainability located in Hanoi, Vietnam. This company was established as a spin off company from the SPIN (Sustainable Product Innovation) project. Their mission is to become a leading R&D, consultancy and capacity building organization in the field of sustainable consumption and production in Vietnam. They have worked with previous graduate students on different projects all concerning sustainability. Two of them *Rob Hoebe* and *Joan Maymi* have worked on a different gasifier type. Their gasifier is much bigger as they optimized it for rice husk as a biomass fuel which can be seen in image 1.4.2 and 1.4.3 below.

Image 1.4.1: Logo of CCS, derived from the SPIN project logo

As the value of rice husk has increased and transportation of this fuel is not profitable (too much volume and little mass) focus has shifted towards gasifiers for pelletized fuel. The latest prototype can be seen in image 1.4.4. Pellets contain much more energy for the same volume as rice husk (as it is compressed). Different fuel types are explored more extensively in chapter 5.5. The development of pellet gasifiers by CCS is presented in appendix B.4.

The research of the previous graduate students is valuable and will be used to improve the design presented in this project. The most important findings from both graduation projects are presented in appendix B.3.

Image 1.4.2: Gasifier by Rob Hoebe

Image 1.4.3: Gasifier by Joan Maymi

Image 1.4.4: CCS 2015 gasifier prototype

1.5 PROJECT APPROACH

Within this chapter the approach towards this project is presented. It consists of three sections, the methodology, the project goals and the project steps.

1.5.1 Methodology

The chosen method should give structure to the presented problem. The method will support in explaining why certain steps are made in the process. There are a lot of tools for designers to choose from when starting with a project. This projects starts by formulating the goals that should be reached in the end and will provide a starting point for the project.

'*Lean*' is used as a method in this project (image 1.5.1). This tool is specifically useful in highly uncertain environments. It will help to successfully make and execute decisions through rapid and continues learning. Due to the uncertainty of how work will be done during the time in Vietnam choosing a method that can cope with unexpected situation might be useful. The lean method takes into account that startup companies, such as CCS, have limited financial recourses. Therefore, it can be beneficial to arrive at conclusions quicker.

Inspired by both the scientific method and business optimization practices, the lean startup builds on three fundamental concepts:

- Build: Drastically shorten each phase of the product development cycle, allowing the product to gain more feedback from tests, customers and the market. Which results in more optimization cycles.
- Measure: Gain feedback from customers in each product development cycle using both qualitative and quantitative techniques.
- Learn: Derive learning from each product development cycle through actionable metrics.

The primary sources of information used for this research:

- Online data from conference slides and proceedings as well as project reports
- Published data in online databases
- First-hand information from gasification experts and researchers
- Vietnamese households

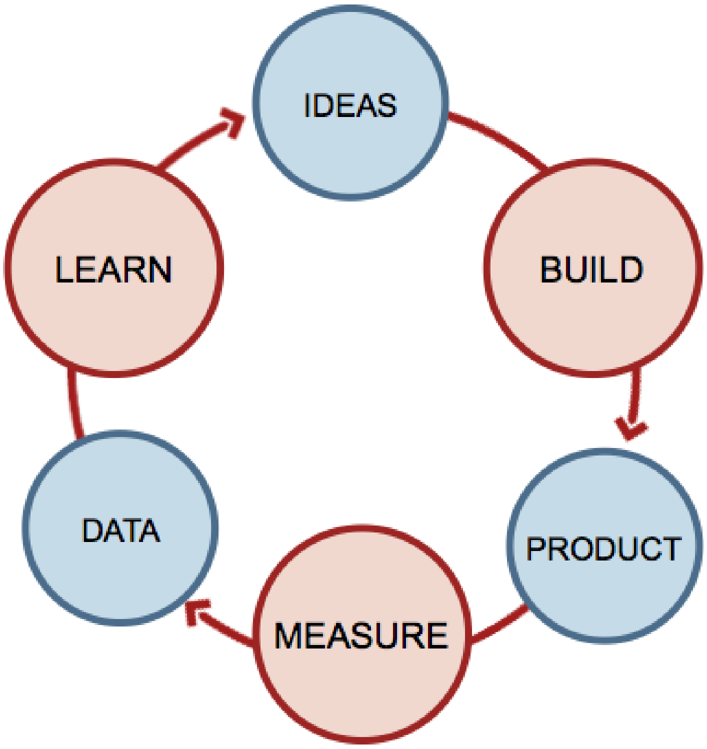


Image 1.5.1: Illustration of the process using Lean methodology

1.5.2 Project goals

The goal of the project is to deliver a gasifier stove design that is ready for mass production. The stove itself will be based on the current prototype but will be improved regarding its user-friendliness, safety and price.

The new gasifier should:

- Fulfill the primary user needs which have to be defined and quantified.
- Learn about mass production in a developing country like Vietnam
- Designed to be produced in mass production
- Being able to sell for an affordable price

At the end of this report the goals will be reflected and assessed to what extend they have been achieved. If certain goals have not been fulfilled advice will be given on future steps that have to be taken.

Image 1.5.2: Vietnamese household cooking on open fire

Image 1.5.3: Production facility outside of Hanoi

Image 1.5.4: CCS gasifier prototype 2015

Image 1.5.5: Dong the Vietnamese currency

1.5.3 Project steps

This chapter describes the steps used for tackling this project. There is a great deal of information available on gasification and culture studies towards living and cooking habits. By mapping the results from these studies, a better understanding of the primary user needs should be obtained. A study on the assessment of products in developing countries (Whitehead, Evans & Bingham, 2014), shows that a lot of projects executed in BoP (Base of the Pyramid) environments initially fail. Reasons for this can vary for each product but often lack one or more of the following attributes; affinity, desirability, reparability, durability, functionality, affordability, usability or sustainability. The lack of these attributes are often the cause of other parties (western companies or even students) involved with local companies that end up with a nice prototype or product and leave it to the local business to proceed further. However, when working with (small) local companies, they often lack the knowledge or resources to execute this phase. For that reason, this assignment will focus on filling this gap between prototype and a commercialized product.

The project will be executed in three phases sub phases will be based using the lean project method:

Step 1 Research phase

- Extensive analysis of the latest gasifier prototype with CAD simulations.
- Define the primary user needs by answering the questions presented. (Appendix A.1)
- Formulate a list of requirements based on the primary user needs.
- Identify problems with the current prototype by different testing methods.
- Provide solutions for the know issues of the gasifier prototype.
- Implement findings on solutions into a new prototype.

Step 2 Concept development phase

- Perform tests with the new prototype and test how well it fulfills the primary user needs.
- Improve the prototype on findings from the user test.
- Optimize design for manufacturing and lower production costs.
- Optimize design for assembly/ maintenance with a modular approach.

Step 3 Detail design phase

- Update CAD model and technical data package.
- Define specific materials.
- Contact suitable production partners locally.
- Investigate distribution channels.
- Start producing first batch to test in the market.

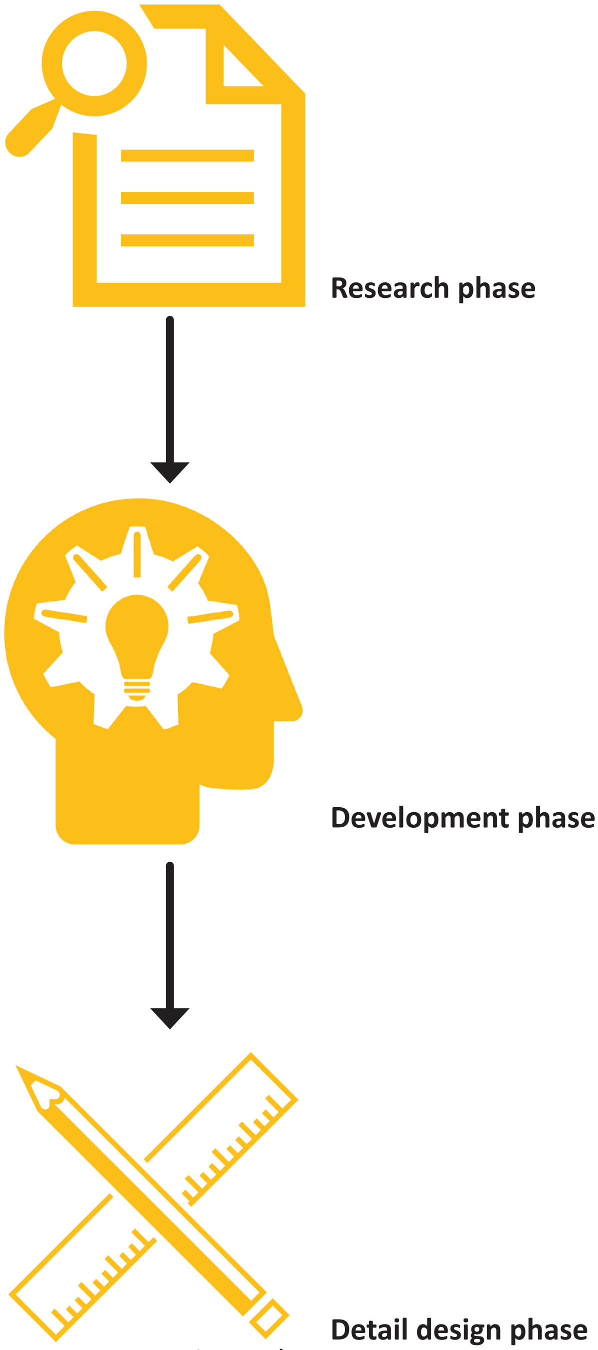


Image 1.5.6: Projects phases

2 ANALYSIS

2.1 INTRODUCTION

In this chapter the first step of the research phase will be executed. The second paragraph (2.2) an extensive analysis of the latest gasifier prototype is presented. This is concluded with a set of design parameters which have to be improved before it can be optimized for production and manufacturing. This was not the model the company presented at the start of this project. Appendix C.2 shows a picture of the model that was analyzed but appeared to be outdated.

The third paragraph (2.3) concludes how advanced cookstoves such as micro-gasification cookstoves are used and received by consumers in Vietnam.

The fourth paragraph (2.4) presents the findings from an observational and literature analysis

The fifth paragraph (2.5) concludes this analysis. It explains why additional steps and research are necessary to gain higher adoptions rates among consumers.

2.2 DESIGN EVALUATION CCS GASIFIER

The current gasifier is based on a TLUD design, with a fuel capacity of 600 grams of wood pellets which enables cooking times from around 45 minutes. It can boil 3 liters of water under 14 minutes and it is estimated that the thermal efficiency is around 43%. Gathering information about the design and performance of this new prototype will help understanding the gasification principle better and make more educated design decisions for a redesign. First the different parts of this stove have been analyzed on their function and producibility. In the next paragraph recommendations are given for improvement. The image below shows the latest prototype with the different parts that will be analyzed. The analysis of each part individually can be found in appendix C.3.

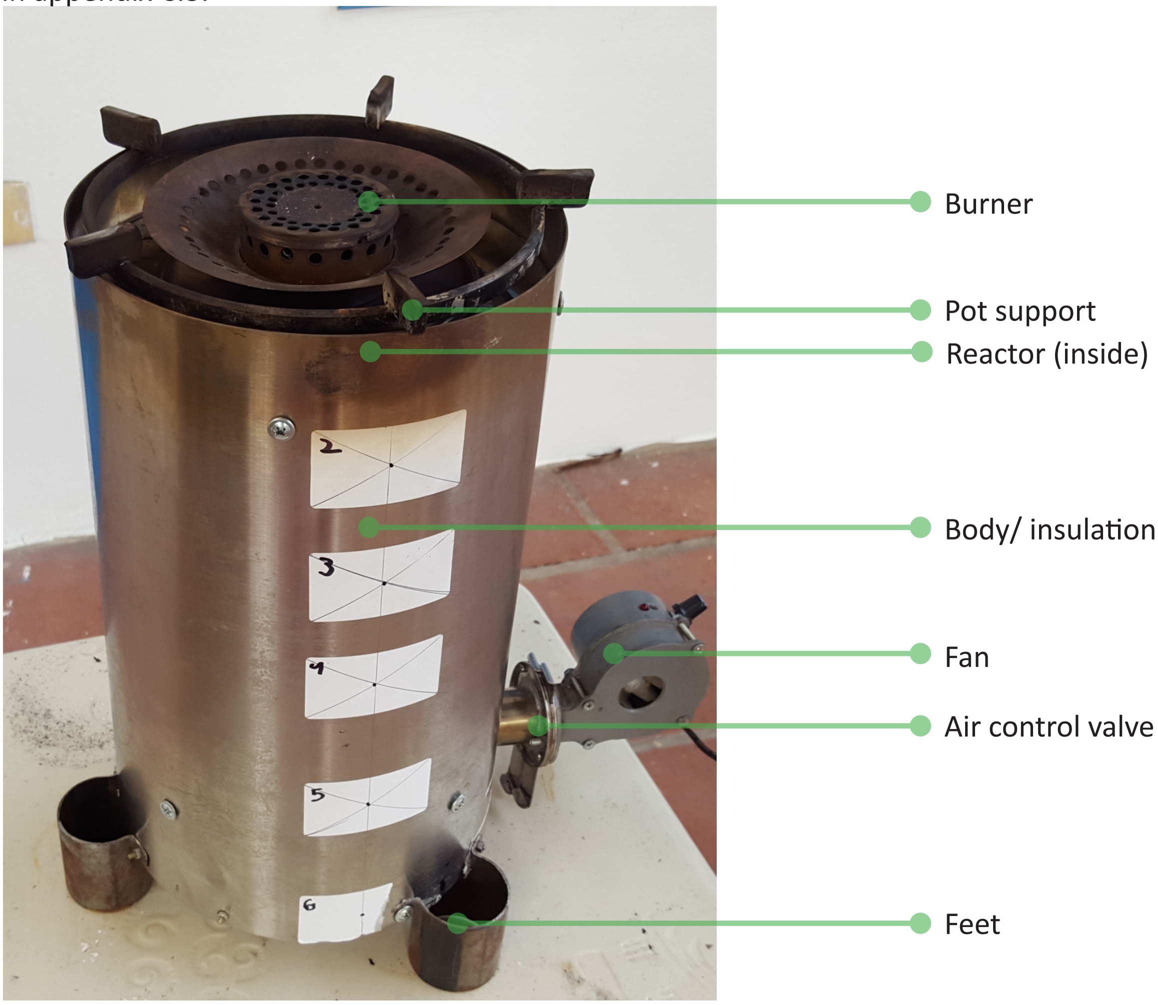


Image 2.2.1: Picture of the 2015 prototype

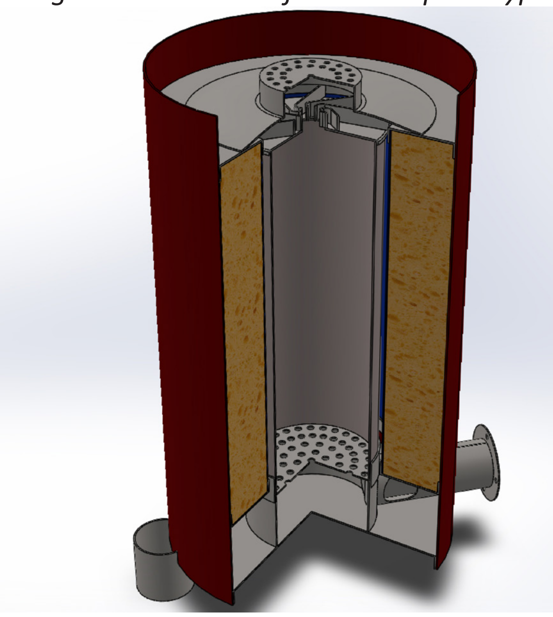


Image 2.2.2: Cut view of the 2015 CCS gasifier

A computer model has been made to support the analysis. In the cross section on the left it can be seen how the gasifier is build up from the inside. With this model a flow simulation has been simulated showing what is happening with the air flow on the inside, this is documented within appendix C.3. By knowing the velocity of the air and the area it travels through, the volumetric flow rate can be calculated and thus the ratio of primary and secondary air can be determined with the following equation:

Velocity = flow rate / area

2.2.1 Conclusion gasifier design

Based on this analysis (appendix C.3) the following points have to be further explored and improved. Prioritizing the different tasks will help dividing the amount of time spend on the subject. A scale of + to ++++ will show how important the subject is considered within this project. The subjects are sorted from important to less important.

Burner design ++++

The burner has to be tested on its performance, durability and usability. After the testing results designs will be made that improve these criteria.

Air control valve +++

Tests should determine if users need to be able to adjust these two air ratios. If they do need it, a valve has to be developed in such a way that users understand how it works and what the effects are when increasing or decreasing one of the two air flows. Another option is to find an optimal air flow ratio and make that one fixed.

Pot support aesthetics ++

As explained two options are available for this feature, when designing one ourselves improving the aesthetics will help with distinguishing the gasifier from the competition. Attention has to be given that it will not be too costly, since the price is the most important criteria.

Material thickness ++

The total weight of the gasifier is almost 6 kg. Decreasing the thickness of the material will reduce both production and transportation costs. The weight does have the advantage that it provides stability to the gasifier as the center of mass is lower when a big pot is placed on top of the stove. If the thickness is reduced methods for keeping the stiffness and strength have to be explored as well.

Fan ++

Chinese manufacturers will be contacted to find a fan that can be bought from large scale suppliers. First the fan made by CCS will be used for initial tests. If this fan can deliver the right performance then it has to be determined what specifications it has regarding pressure, volumetric flow per minute etc. There are two important criteria when selecting a fan from manufacturing partners:

- Does it have the right performance?
- Can they give a good competitive price (aiming at less than a dollar/ unit)?
- Will they give a warranty on their product?

Insulation +

Different insulation alternatives can be explored in order to make an educated decision on the best method.

Grade +

Other materials such as standardized perforated sheets of metal might provide a more durable solution. The grade should also be able to be replaced if it gets damaged.

2.3 ADVANCED COOKSTOVES IN VIETNAM

Rural households in Vietnam rely heavily on solid biomass as a means for cooking. Initial cookstove programs were aimed at combating deforestation but this has been questioned by some as this correlation differs per area.

The distribution of improved cookstoves often aims at advantages that the western society would perceive as important, while this might not be perceived as an issue due to social patterns. For example it is not in the males direct interest that his wife and children spend less time collecting wood, have shorter cooking times or high efficient clean combustion. In some areas there could be a financial gain, for example if households have to buy their fuel then it is much more interesting for the male to invest, though initial investment cost should not be too high. Therefore, households are generally more willing to adopt an advanced cookstove if they are already purchasing biomass fuel, if fuel is free then they should be persuaded with other advantages that are important to them.

In Vietnam there has not been any large scale distribution of improve cookstoves, except for the biogas program funded by the Dutch development organization SNV. However, programs in cooperation with Vietnam Women's Union in northern Vietnam have distributed around 30 000 stoves with a design much like the Chinese improved cookstove(GACC, 2012) (ICS).

A case study on village fuel use and variations (Vahlne & Ahlgren, 2014), investigates the possible deployment of an advanced cookstove program in the northern mountainous area of Vietnam. It states that villages which are depending largely on purchased biomass for fuel are the most suitable market. The same study also shows that there is a substantial difference to actual reduction of used biomass for cooking among people and relatively nearby villages. This might be due to improper usage of the stove. Therefore, it is important to carefully consider which village to target when deploying an advanced cookstoves.

Image 2.3.1: Discarded old gasifier stove in a Vietnamese home

2.4 SITUATION ANALYSIS

This paragraph shows the most important results of the analysis to evaluate the situation around the company CCS and micro-gasification cookstoves. The complete analysis is documented in appendix C.4. Most of the internal analysis is based on observations during the time working in Vietnam. Other sources of information such as news reports and scientific articles provide insights in the external context of this project. The most important points are presented in the table below.

Positives	*Chances*
• CCS has fast and easy access to prototype and test different ideas and concepts in their workshop. • Performance of the current version of the CCS gasifier stove is good (close to tier 4) compared to other stoves in the market. • CCS has knowledge on the consumer market in Vietnam.	• Multiple countries plan or have started programs for the distribution of advanced cookstoves. • Pellitizer machines of biomass fuel are not expensive and are sold for under 3000 USD. • People are becoming more aware of the issues caused by their traditional ways of cooking, especially regarding their health.
Negatives	*Dangers*
• CCS has a lack of proper documentation of test results and designs. • There are no established sales channels for the gasifier. • All the gasifiers that have been developed got stuck in the prototyping phase.	• The price of biomass fuel cannot be controlled and might increase when demand increases. • Consumers fail to see the long term economic benefits of using a gasifier cookstove especially when the initial investment is relatively high. • When used improperly, a gasifier can potentially be dangerous for consumers. For example, when the flame blows off the gasifier will keep on generating toxic gas spreading it in the room.

Table 2.4.1: Internal and external analysis of the CCS micro-gasification stove

This analysis shows the complexity behind the gasifier project. As can be seen in the dangers, not all parameters can be controlled. For example, if the goal is reached in developing a gasifier design that can be produced using mass production techniques and even fulfills all the user needs, there are still some other challenges to overcome:

- Who will invest in setting up the initial production line?
- How will the product be distributed?
- How will the fuel be distributed?
- How will users be convinced into investing in a new cooking device?
- Who are the consumers and what are their specific needs?
- Will consumers operate the device correctly?

These are just some of the questions that need to be answered for a successful implementation of a advanced cookstove, although some fall out of the scope of this project. However, it is clear that the project does not stop with just one final design, but small steps can be made in making a step towards reaching this goal.

2.5 REFINED PROJECT APPROACH

The project started off with the assignment formulated as: Bridging the gap between a lab prototype gasification cookstove and a commercialized product. By fulfilling and implementing the primary user needs into a final design. In addition the product should be produced using low cost mass production techniques. Although this is still the goal of the project, it is clear that more work has to be done to the current gasifier design and additional research is needed to make the product fit with the context is has to operate in. This can even mean that the basic principle of having a batch operated stove could be questioned.

First the latest prototype of the stove will be tested towards efficiency, usability and performance. Issues will be identified first hand and will later be translated to a list of requirements for a new design.

Secondly, research will be executed towards gasification in order to gain a better understanding on what parameters can be changed when improving the gasification process.

Thirdly, an exploratory study will give a better understanding of the context of both the Vietnamese market as well as the international market. Different biomass fuels should be explored on how they influence the gasification process. This analysis will result in a clear overview of the different market segments in Vietnam. As seen with other stove programs who failed to identify and adopt the primary user needs of their target segment, they have to be formulated for a better chance of market adoption.

After these steps have been executed the project steps, as presented in the previous chapter, can be continued and move to the development phase of the gasifier.

3 STOVE RESEARCH

3.1 TESTING METHODOLOGY

3.1.1 Introduction

In this chapter the gasifier will be tested numerous times to gain insights in the gasification process and the performance of the stove. First the methodology and goals of the tests will be described after which conclusions and recommendations will be given for the next phase.

Test 1 Exploratory testing

The goal of this test is to get familiarized with the gasification principle. The following aspects will be explored:

- Operating the gasifier
- Surface temperature
- Temperature inside the reactor
- Quality of the flame with high- and low power fan
- Position of the flame

Test 2 Air flow testing

The goal of this test is to evaluate the performance of the fan, the effect of fuel on the air flow and gain insights in the primary and secondary air division. The following aspects will be explored:

- Volumetric flow of the air in cubic meter per minute
- Static pressure in mm H2O

Test 3 Boiling performance test

A boiling test will be executed in order to benchmark the stove its performance regarding the boiling of water.

Test 4 User testing

User tests will provide information on how the consumer perceives the gasifier, and will identify if there are any problems, or misuse during a cooking operation.

Test 5 Efficiency testing

Having limited equipment in Vietnam a test has been developed to determine the efficiency. In theory it can be calculated how much of the energy from the fuel (the calorific value) is effectively transferred towards heating the water.

3.1.2 Goals

The goals of these experiments that should be met are to find quantitative data on the following subjects

- Usability
- Performance of the stove
- Durability of the parts
- Body surface heat
- Effectiveness of the insulation

3.2 TEST 1: EXPLORATORY TESTING

The test was set up in the configuration shown in image 3.2.1 below. Every 5 minutes the temperature was measured and near the end of the test, the temperature inside the reactor was measured as well.

Image 3.2.1: Test setup with equipment

Operating the gasifier

1. First the reactor is taken out of the gasifier and filled with about 600 grams of wood pellet. At the top some rice husk is added as a starting material. The fan is turned down to a minimum.

2. After the rice husk burns the wood pellets the first part of the burner is placed on top of the reactor using a plier.

Image 3.2.2: Step 1

Image 3.2.3: Step 2

3. The valve of the secondary air is opened and the fan speed is increased gradually. Some of the burned rice husk and paper is flying around due to the increased fan speed.

4. The next step is to place the top part of the burner on top. Doing this you have to make sure the flame does not extinguish by slowly placing this part on top.

Image 3.2.4: Step 3

Image 3.2.5: Step 4

5. The gasification process gets better over time, both the primary and secondary air valves did not have to be changed much. The total operating time was around 45 minutes and created a semi blue flame. The flame did not burn outside of the burner which made the burner glowing red hot.

Image 3.2.6: Step 5

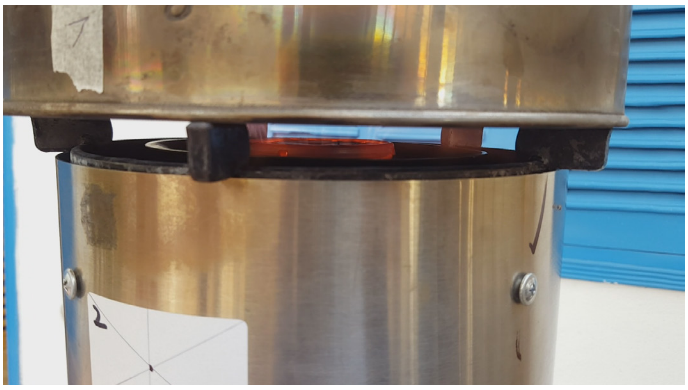


Image 3.2.7: Step 5 pot placement

6. After the gasification process is finished the burner is removed using the pliers to empty the remaining char.

7. The reactor is removed from the gasifier and emptied. The only char left is from the rice husk, the wood pellets seem to be completely burned. After this the reactor is placed back in the gasifier and the fan is set to its maximum to cool all the parts.

Image 3.2.8: Step 6

Image 3.2.9: Step 7

Surface & reactor temperature

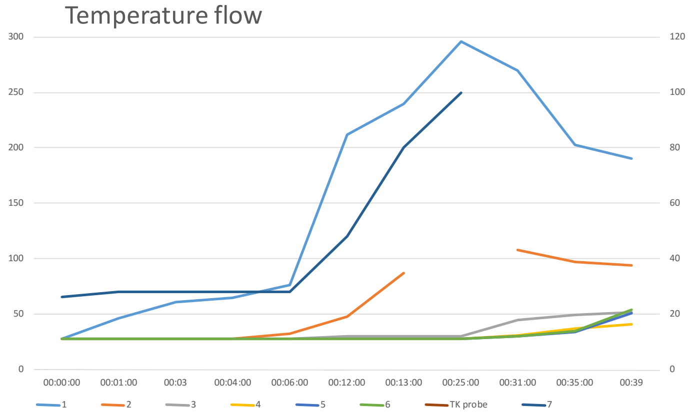
Using the infrared heat-gun the surface temperature of the gasifier was measured. Because the measurement is not accurate on reflective surfaces six stickers were placed on the gasifier. Every five minutes the surface temperature was measured. The results are given in graph 3.2.1 on the right.

Measuring point 1 (the sticker was burned and therefore not visible anymore) became very hot with a maximum temperature of 296 °C. The reason for this point becoming this hot, is that it is does not have thermal insulation. The other points did not become that hot with a maximum temperature of 106 °C.

The temperature inside the reactor reached almost 1300 °C.

The stove did remain quite hot for about 30 minutes. This means that a lot of thermal energy is stored within the materials of the gasifier such as the insulating glass wool.

Image 3.2.10: Body with stickers for measurement



Graph 3.2.1: Diagram of body surface temperature

3.3 TEST 2: AIRFLOW TESTING

To investigate the possibility of a fixed primary/ secondary airflow ratio, it has to be determined how much primary air is flowing through the reactor and the amount of secondary air that arrives at the burner, with changing amounts of fuel. For this test the following equipment had to be manufactured:

- The volume of air was measured with a water flow meter
- The pressure was determined with a mono meter.
- A special lid for the reactor tube to measure the primary air flow.
- A lid covering both the primary and secondary air flow.

3.3.1 Method

Different setups can be measured with this equipment. The airflow can be controlled with the valves on the gasifier. For this test we used three different positions:

- Primary air open, secondary closed
- Primary air closed, secondary open
- Primary air open, secondary open

The following tests have to be performed to gather the necessary data. All tests have been executed for three different fuel levels; Full, half full and empty. A full fuel batch consists of 734 g of wood pellet.

- Maximum air flow of the fan connected directly to the water flow meter.
- Maximum pressure of the fan connected directly to the mono meter.
- Primary open, secondary open reactor measurement.
- Primary open, secondary closed reactor measurement.
- Primary closed, secondary open total measurement.
- Primary open, secondary open total measurement
- Primary open, secondary closed total measurement.

3.3.2 Goals

These following goals should be defined after the testing:

- The performance of the CCS manufactured fan.
- Resistance of the fuel on the primary air flow.
- Efficiency of the airflow and pressure through the primary and secondary airflow channels.
- The primary/ secondary airflow ratio in terms of volume air.

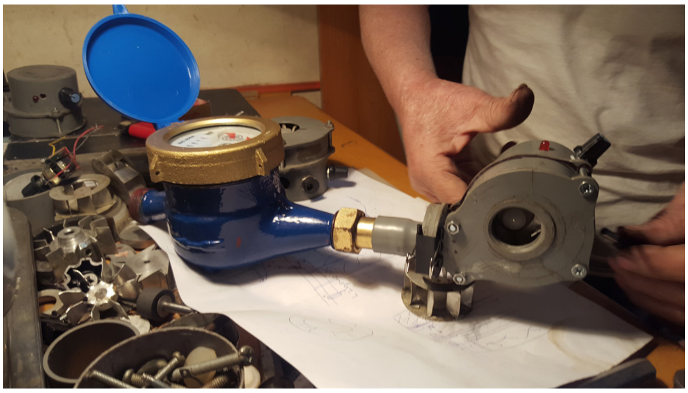


Image 3.3.1: Air volume measurement device

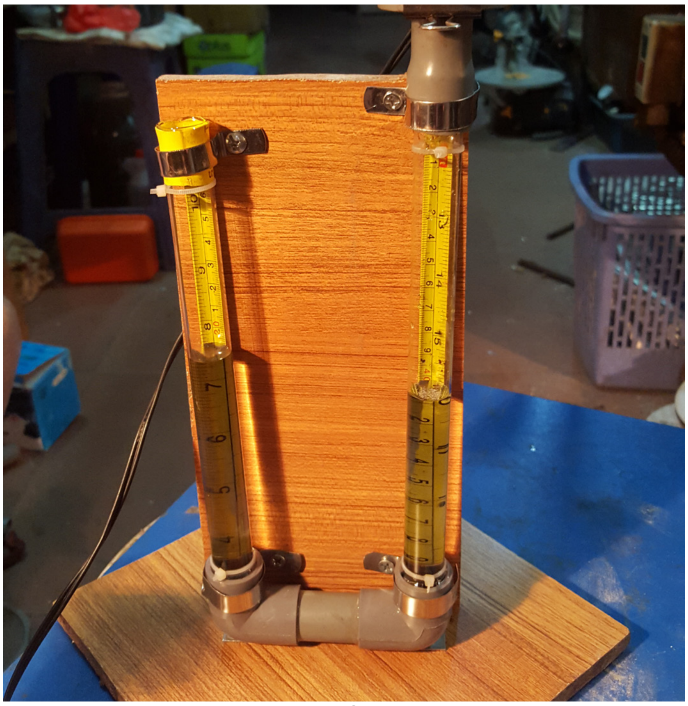


Image 3.3.2: Mono-meter for pressure measurement

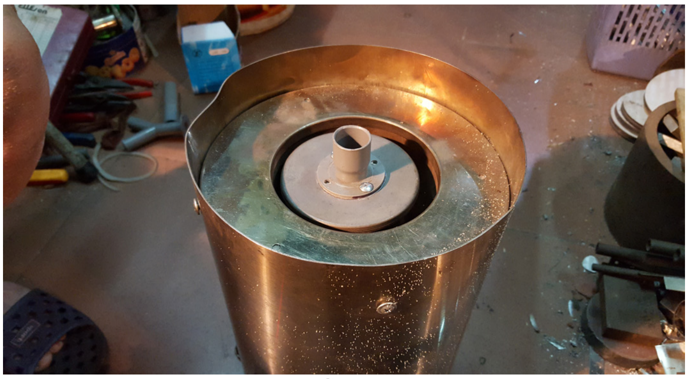


Image 3.3.3: Primary airflow measurement lid

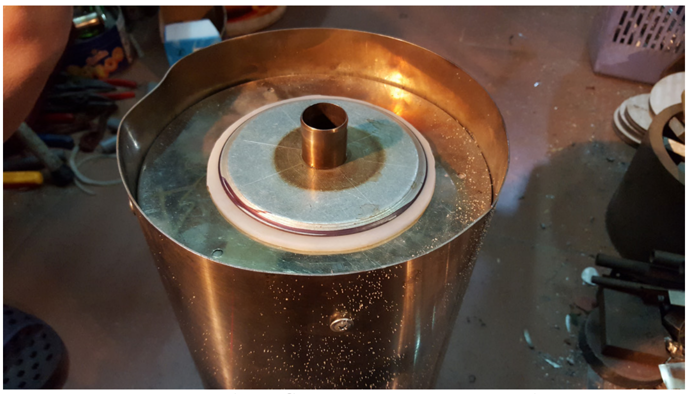


Image 3.3.4: Total airflow measurement lid

3.3.3 Results

The results have been written down in the table 3.3.1 below. The pressure difference between the bottom and the top of an incompressible fluid column is given by the incompressible fluid statics equation:

$$\Delta P = p * g * h$$

Where g is the acceleration of gravity (9.81 m/s2).

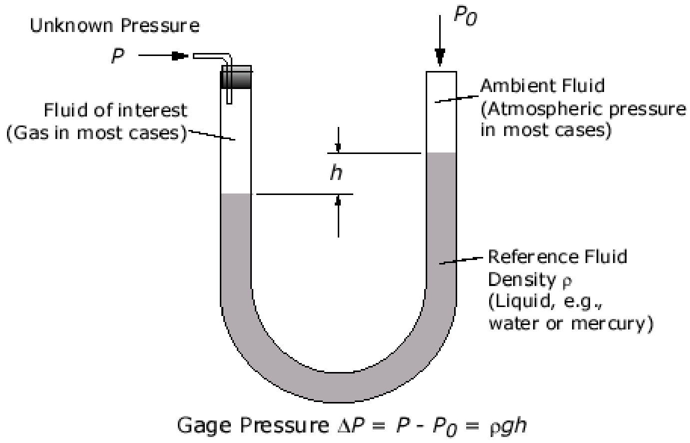


Image 3.3.5: Working principle of a mono-meter

Full fuel configurations	**mm H20**	**m^3/min**
Primary *open*, secondary *open* reactor measurement	10	0,22
Primary *open*, secondary *closed* reactor measurement	12	0,3
Primary *closed*, secondary *open* total measurement	18	0,31
Primary *open*, secondary *open* total measurement	22	0,335
Primary *open*, secondary *closed* total measurement	22	0,32

1/2 fuel configurations	**mm H20**	**m^3/min**
Primary *open*, secondary *open* reactor measurement	8	0,28
Primary *open*, secondary *closed* reactor measurement	12	0,3
Primary *closed*, secondary *open* total measurement	19	0,33
Primary *open*, secondary *open* total measurement	22	0,35
Primary *open*, secondary *closed* total measurement	22	0,33

Empty fuel configurations	**mm H20**	**m^3/min**
Primary *open*, secondary *open* reactor measurement	10	0,28
Primary *open*, secondary *closed* reactor measurement	12	0,3
Primary *closed*, secondary *open* total measurement	22	0,3
Primary *open*, secondary *open* total measurement	22	0,37
Primary *open*, secondary *closed* total measurement	20	0,38

Fan performance	
Maximum pressure	34 **mm H20**
Maximum volume	0,7 **m^3/min**

Table 3.3.1: Test results different configurations

3.3.4 Conclusion

When comparing the results, the most interesting finding is that the amount of fuel has a neglectable influence on the volume of the primary air. This is useful when fixing the air ratio because it will not change during operating when the fuel is consumed.

The second finding is that most of the air that is going through the gasifier is primary air. This can be determined when looking at the reactor and the total measurements where both of the valves are open. With a full fuel batch, 0,22 m^3/min is flowing through the primary air and 0,335 m^3/min is the total measurement. This means that only 0,115 m^3/min is flowing through the secondary airflow. Resulting in a secondary/ primary air ratio of 0,52.

There is a notable amount of loss when looking at the amount of volumetric air that comes out of the primary and secondary air compared to the maximum capabilities of the fan.

3.3.5 Discussion

The executed tests give a good estimation on the influence of the amount of fuel on the pressure and volume of air during operation. It has to be noted that not all the equipment used have the same accuracy as when it would be tested in professional laboratory. The readout of the pressure on the mono-meter is sometimes difficult to determine the exact value. The lids are pressed on by hand and might not seal completely which also influences the results.

For the volumetric measurement of the air a stop watch was used and the rotating cycles on the water flow measurement device were counted. After one minute the lid was taken of the gasifier, but as there was still some air flowing the indicators did not stop immediately. Therefore, it had to be carefully monitored, but still small inaccuracies cannot be avoided.

3.3.6 Fan from manufacturers

The performance of the fan produced by CCS was tested. With this information multiple fans from a manufacturing supplier in China were ordered (see appendix D.1). The 75 mm fan shows to be a good fit for this gasifier. Negations about the price led to 1 dollar per piece when 5000 units would be ordered.

3.4 TEST 3: BOILING PERFORMANCE TEST

For this test 3 liter of water was raised to its boiling temperature. The test was executed with the following steps:

- Fill a stainless steel kettle with two liters of water (~20 degrees Celsius)
- Remove the reactor from the gasifier
- Fill the gasifier with 650 g of wood pellets
- Put 20 g of rice husk on top
- Mix the wood pellets and rice husk a little bit so that rice husk gets in between the wood pellets
- Place the reactor in the gasifier
- Connect the fan to the air tube
- Connect the adapter to the fan and change the speed of the fan to low power mode
- Close the secondary air supply and open the primary air valve
- Use paper to start the combustion process of the rice husk and wood pellets
- After 3 minutes gradually increase the speed of the fan
- After 7-10 minutes the burner is placed on top using the pliers
- Open the secondary air valve and close the primary air supply half way
- Start boiling test at 16:10 minutes since the start
- Water reached boiling temperature after 22:35 minutes
- Cool the kettle and put two fresh liters of water in the kettle
- Start boiling test at 26:35 minutes since the start
- Water reached boiling temperature after 32:50 minutes
- Total stove operating time ~50 minutes since the start

Image 3.4.1: Gasifier with kettle placed on top

3.4.1 Conclusion

The gasifier can boil two liters of water within 5:25 and 6:15 minutes in a stainless steel kettle. Compared to other stoves such as the beehive coal or LPG where it would take up to 18 and 10 minutes respectively.

3.5 TEST 4: USER TEST

Some user tests were executed with the prototype of the gasifier stove. The goal of this research was to evaluate the perception of the stove by the user. People were asked to boil water and to prepare a meal with the gasifier. The tests were executed by Hai from CCS, a template with questions were provided for him to fill out and observe. See appendix D.3.

From video observations and the questionnaire, it became clear that the gasifier was well perceived by the local community. The ability to control the strength of the flame reminded them of the functionality of a normal LPG gas stove. Some small cooking equipment did not fit on pot support and it appeared that the pots were too high from the flame. This did allow users to clearly see the flame as they adjusted the fan speed.

Image 3.5.1: User interacting with the stove adjusting its performance


Image 3.5.2: Positive emotion of the user interacting with the stove by adjusting its performance


Image 3.5.3: CCS Employee Hai interviewing a user in Ha Giang


Image 3.5.4: CCS employee Hai interviewing the users after the test

3.6 TEST 5: EFFICIENCY

3.6.1 Introduction

Efficiency of a gasifier stove can be calculated using several methods. One method has been explored as this could be executed using limited equipment available in Vietnam.

Image 3.6.1: Pelletized fuel

Materials

- Scale
- Pot (aluminum for this test) that can contain 5-liter of water
- Micro-gasification cookstove prototype
- Temperature measurement device
- Wood pellets
- Timer

Method description

Within this method the efficiency of gasifier stoves can be determined by calculating the heat gained by the water and the amount of fuel consumed during this process. In other words this means, dividing the calorific value of the wood pellets, which is a theoretical value often provided by the supplier, and the heat absorbed by the water in the pot during the test.

Two states during the heating process are classified as Low Power Phase (LPP) and High Power Phase (HPP). In this first test only the HPP is used to determine the efficiency due to the time that is available for these tests.

In HPP, heating of water from the initial temperature (T1) to the boiling point (Tb) is determined. During this phase, water in the vessel gains energy in the form of heat from the burning fuel with the help of the stove. The energy that is required to raise the temperature of the mass of water (Mw) from T1 °C to Tb, can be calculated by multiplying the mass of the water with the specific heat capacity of water and the difference in temperature.

Energy content of the fuel consumed during each process is the input energy for these phases. Overall efficiency is calculated by dividing the output energy by input energy. In this process the heat gained by the vessel in which water is boiled should also be accounted for.

Image 3.6.2: Big pot containing 5-liter of water during the test

3.6.2 Calculations

The following calculations will be used as input to determine the efficiency in the HPP:

Heat gained by vessel	=	Mv * Sv * (Tb - Ti)	[Joule]
Heat gained by water in HPP	=	Mw * Sw * (Tb - T,)	[Joule]
Heat gained by vaporized water	=	Msteam * LWboil	[Joule]
Energy of fuel	=	(Mfule * Kfuel)	[Joule]

Where:

Mv	=	Mass of vessel	[Kg]
Sv	=	Specific heat capacity of vessel	[J/kg°C]
(Tb – T1)	=	Change in temperature (from Tl to boiling Point)	[°C]
Mw	=	Mass of water	[Kg]
Msteam	=	Mass of the vaporized water	[Kg]
Sw	=	Specific heat capacity of water	[J/kg°C]
LWboil	=	Latent heat of boiling of water	[J/kg]
Mfuel	=	Mass of consumed fuel	[Kg]
Kfuel	=	Calorific Value of Fuel	[J/kg]

Constants taken for calculations:

• Specific heat capacity of water	(Sw)	4190	[J/kg°C]
• Specific heat capacity of aluminum	(Sv)	125	[J/kg°C]
• Calorific value of wood pellets	(Kfuel)	17505	[kJ/Kg]
• Heat of vaporization of water	(LWboil)	2660	[kJ/Kg]
• Weight of the big pot	(Mv)	0,991	[Kg]

Measured during test:

- Mass of the *water* at the beginning of the measurement
- Mass of the *water* at the end of the measurement
- Mass of the *stove* at the beginning of the measurement
- Mass of the *stove* at the end of the measurement
- Time the pot is put on the stove during the measurement
- Time water in the vessel reaches its boiling temperature

Efficiency (HPP) = (Heat gained by vessel + Heat gained by water in HPP) / (Quantity of fuel consumed * Unit calorific value of fuel)

Efficiency (HPP) = (MW*SW* (Tb - T1) + Msteam *Lwboil + Mv * Sv * (Tb - T1) + Msteam * LWboil) / (Mfuel* Kfuel)

3.6.3 Efficiency testing

Using the theory presented, the efficiency of the stove is calculated. The data in the table below shows the measurement data from the test. The Stove was able to boil 4.8 liters of water within 11 minutes and 35 seconds. Readings from the scale showed that at the end of the test 220 grams of wood pellets was used. This results in a total efficiency of 43%.

	Measurement	Data measured	Unit
1	Mass of the *water* at the beginning of the measurement	4,8	Kg
2	Mass of the *water* at the end of the measurement	4,6	Kg
3	Mass of the *stove* at the beginning of the measurement	6.76	Kg
4	Mass of the *stove* at the end of the measurement	6.54	Kg
5	Time the pot is put on the stove of the measurement	11:45	min
6	Time water in the vessel reaches its boiling temperature	22:10	min

Table 3.6.1: Measured values of the efficiency test

	Output	Formula	Result	Unit
1	Heat gained by vessel	Mv * Sv * (Tb - T1)	72	KJ
2	Heat gained by water in HPP	Mw * Sw * (Tb - T1)	1614	KJ
3	Heat gained by vaporized water	Msteam *Lwboil	0,45	KJ
4	Energy of fuel	Mfuel * Kfuel	3851	KJ

Table 3.6.2: Calculated values of the efficiency test

3.6.4 Discussion

The test and theory provided insights regarding the fuel use and the influence of the pot material on the boiling time. It is now clear that statements made by stoves regarding their time to boil of a certain amount of water should also provide information about the equipment they used for their test.

The calculated efficiency of 43% is greatly influenced by the accuracy of the measurement devices. Small variations in fuel consumption will already change the outcome a lot. The 43% thermal efficiency is just below the “Tier 4” scale which requires a minimum of 45% thermal efficiency in the high power phase. Using a large scale is a good idea as the weight could be measured in real time. However, since it is not an electronic scale it does not provide the accuracy that is needed for this test. A new test with a more accurate scale should be executed thereby following the WBT test protocol as described in chapter 4.3. This test covers three phases giving a more accurate indication of a stove its performance.

3.7 EVALUATION TESTING PHASE

From this first analysis phase it has become clear that the current state of the gasifier does need more improvement regarding usability and performance. The problems listed in the previous chapter 2.2.1 should therefore first be resolved before moving to mass production and implementation of the gasifier.

Burner design

The burner appeared to be degrading rapidly. After just a few times of usage the metal was oxidizing due to the heat. Making the flame burn on top of the burner holes does not only increase the durability but also the efficiency.

Air control valve

A new valve has to be developed that has a better division of the two air flows with improved controls. Tests will then show a more accurate result. It has been proven that a fixed ratio is possible as the amount of fuel in the reactor has almost no influence on the resistance to the air flow

Pot support

Two types of pot support were used during the different tests. One of them was too high from the flame, which reduced the efficiency. Both pot support rings were not suitable for smaller cooking equipment. A different solutions has to be explored, also regarding the production cost and aesthetics.

Fan

As mentioned, fans from a Chinese manufacturer have been ordered and can be tested on their performance. The fan of CCS has a static pressure of 34 mm H2O and can blow 0.7 m^3/min (24 CFM).

4 GASIFICATION

4.1 GASIFICATION

4.1.1 Introduction

Although gasification seems a complex principle, people are very much familiar with it. Whenever a match is lit or campfire is started, solid biomass fuel (like wood) is being gasified. Gasification is a thermal chemical process which converts biomass materials into gaseous components which is referred to as 'Syngas". This gas containing carbon monoxide, hydrogen, methane and some other inert gases can even be used to power a diesel engine. The basic function of a gasifier stove is to make this process as optimal as possible in order to have less toxic emission and the fuel is burned with a higher efficiency.

4.1.2 Types of gasification

Before looking at the gasifiers in the market it is important to know that there are different working principles behind gasification. These different types can be used depending on the purpose of your gasifier. These are all based on fixed bed gasifier solutions. The basic working principle of each of these gasification methods is to fill a container (reactor) with biomass fuel where the biomass is burned contrary to the biomass layer.

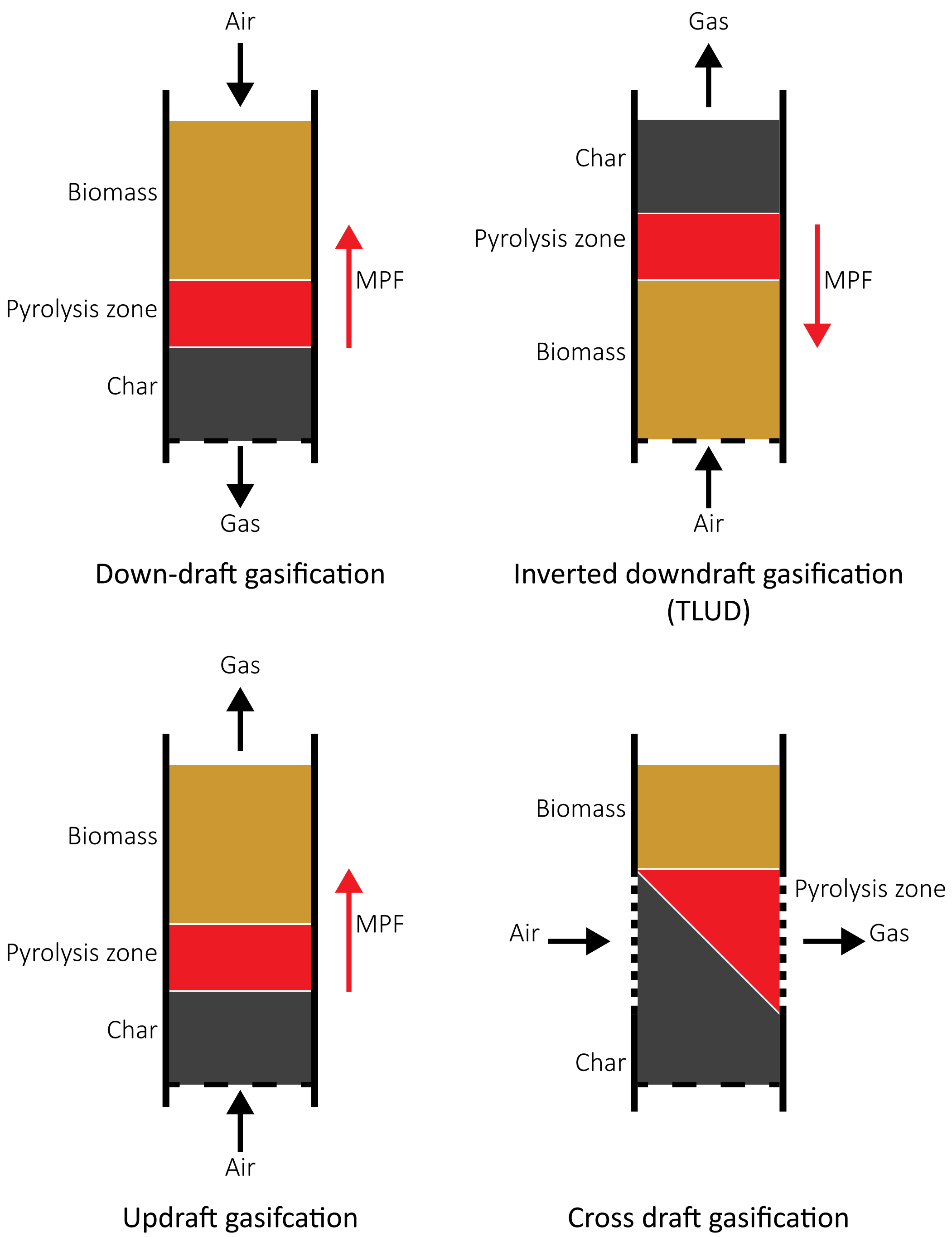


Image 4.1.1: Different types of fixed bed gasifiers

4.1.3 TLUD gasification

The most common working principle of micro gasifiers that is used for cooking purposes is top-lit updraft (TLUD). *Top-lit* means that the fuel is lit at the top of the fuel-bed. This is convenient for cooking as the fire is directly beneath the bottom of the pot. *Updraft* means that the combustible gases flow upwards, while the migrating pyrolytic front (MPF) moves downwards. The hot gases have a natural flow upwards as they are lighter than ambient air, this can create a natural draft for any secondary air. A fan can assist this process by adding more air to the MPF increasing the combustion and forcing the air up to the pot.

The different stages of the TLUD principle are visualized in image 4.1.2 below. This process shows a batch operation and can be divided into seven stages.

1. Dry fuel is loaded into the reactor. The fuel can consist of many sorts of biomass, however the operation works best when the fuel has a low moisture content, homogeneous shape etc. See chapter 5.5 for more information on suitable fuel types for gasification.
2. The top is lit with starter material such as paper or liquids alcohol. The heat will pyrolysis the top layer of the fuel and starts generating the syngas.
3. Char is created on top and the MPF starts moving down. The fuel is prevented from direct combustion due to the lack of oxygen provided by the primary air flow. At the top, outside the reactor, additional oxygen from the environment or secondary air is added to the gas. This causes the complete combustion of the syngas when the right amount of air is added.
4. As the MPF continues to move downward it keeps creating a constant amount of syngas as the amount of fuel that is burned is limited to the diameter of the reactor. At this stage temperatures have risen higher creating better “quality” syngas. The chemistry behind this is explained in paragraph 2.1.5.
5. Near the end of the batch operation the MPF approaches the bottom of the fuel-bed. The process remains constant until this point and might have a small increase in gas production as the radiant heat of the char is reflected back from the grate and the bottom.
6. At the end when all the MPF has reached the bottom there is no more fuel for the pyrolysis. Some gas might still be produced, it can be observed that when only char is being burned only blue flames come out at the top. This indicates that the carbon monoxide is being burned and the yellow color from fine particles is gone. This stage can be extended with forced primary air where you continue to burn the char and created CO.
7. Depending on the fuel and how long stage six is continued, there might be some char left after the process. When using rice husk for example there will be about 17-26% of the original volume left, for wood or wood pellets this is only 0.3 - 2%.

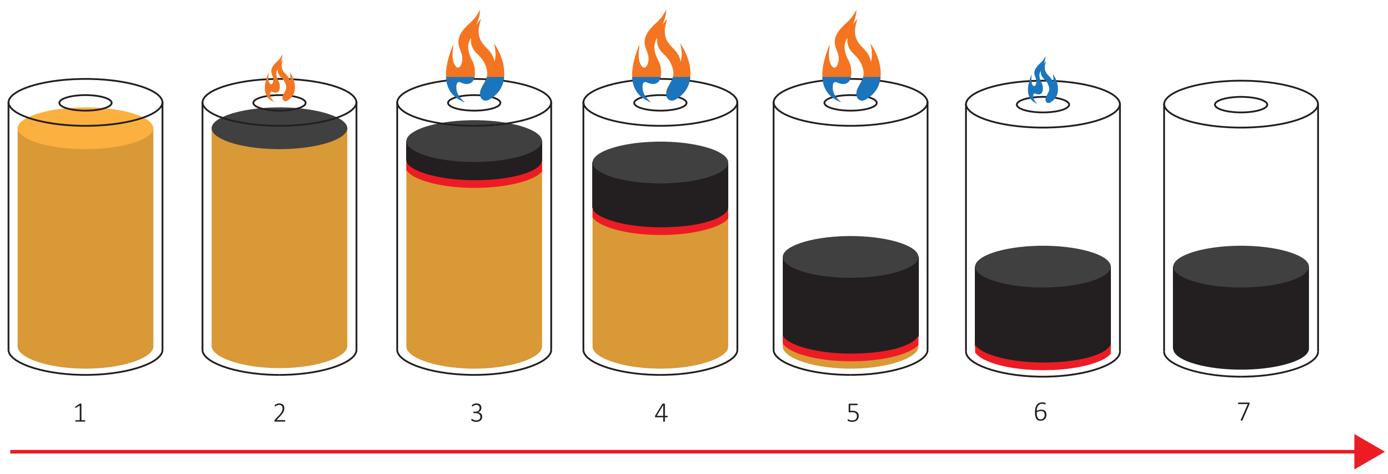


Image 4.1.2: Stages of a Top-Lit Updraft gasifier stove

4.1.4 Basic gasification process

Going deeper into the gasification process that takes place inside a reactor four distinct process take place. In most of the gasifiers the reactor will consist out of a metal or ceramic tube or padding in which the biomass fuel can be loaded. The four processes within gasification are:

1. Drying of the fuel

The biomass fuel is heated and dried, depending on the type of gasification this happens in a different location within the reactor. For downdraft gasifiers this happens at the top of the gasifier unit and for inverted downdraft this happens at the bottom. Heat transfer from the reaction zone will reduce the moisture contained in the biomass to a level below 20%. The water vapor will follow the direction of the gas and is mixed in the oxidation zone. Part of it may be reduced to hydrogen and the rest will end up as moisture in the gas.

2. Pyrolysis

After enough moisture has been evaporated the biomass fuel enters a second zone called the "pyrolysis zone". This creates the gaseous products from volatilization which is partially burnt with the existing air.

Both pyrolysis and gasification turn biomass into an energy rich fuel by heating it under controlled conditions. In contrast to incineration, which fully converts the biomass into energy (in the form of heat) and ash, these processes deliberately limit the conversion so that combustion does not take place directly. Instead, the biomass is converted into two intermediates, pyrolysis gas (syngas) and charcoal. In a Top-Lit updraft stove such as the CCS gasifier stove, the produced syngas is mixed with additional oxygen after which it is directly combusted for cooking purposes.

3. Oxidation (combustion)

Introduced air in the oxidation zone contains besides oxygen and water vapors other gases such as nitrogen and argon. These cases are considered to be non-reactive with the fuel. This phase takes place at temperatures ranging between 700 - 2000 degrees Celsius. The reaction formula can be seen as reaction 1 on the next page.

4. Reduction

In this zone a number of high temperature chemical reactions take place in the absence of oxygen. See reaction 2 until 5 on the next page. Looking at the energy released in this phase shows that heat is required during this process. Hence the temperature of gas goes down during this stage. For complete gasification all the carbon is burned or reduced to Carbon Monoxide, which is a combustible gas, and some other mineral matter is vaporized. The remains are ash and some unburned carbon.

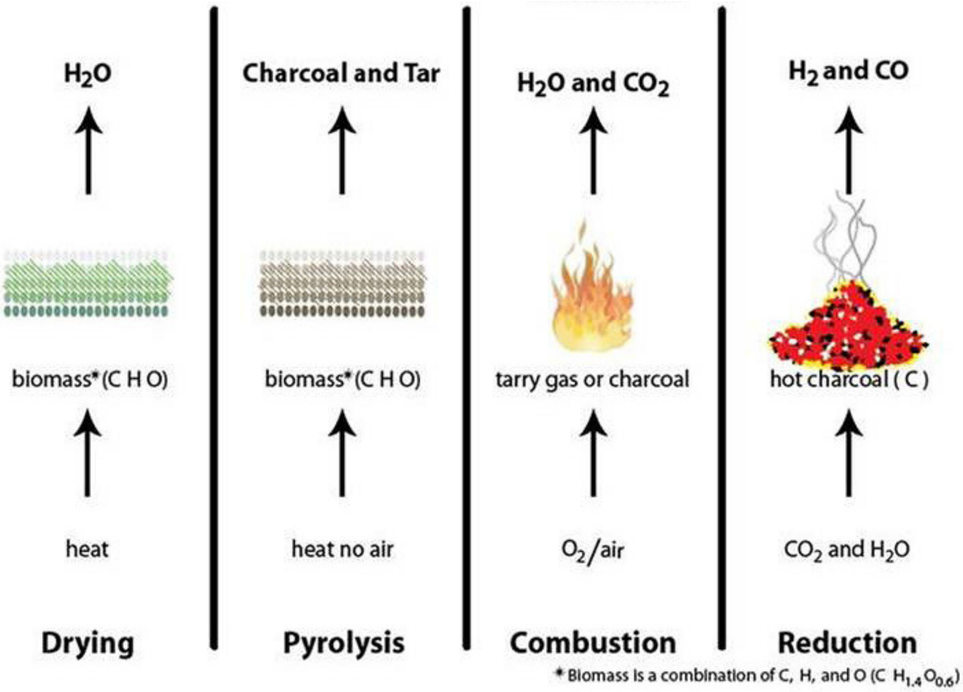


Image 4.1.3: Four processes of gasification

4.1.5 Gasification formulas

Gases produced during gasification compose of: carbon monoxide, hydrogen, methane, carbon dioxide, and water vapor. The gasification process can be represented with the following chemical reactions:

Chemical reactions:

1.	$C + O_2 \rightarrow CO_2$	(Combustion reaction)
2.	$C + H_2O \rightarrow CO + H_2O$	(Coal reaction, water gas reaction)
3.	$CO + H_20 \rightarrow CO_2 + H_2$	(Water shift reaction)
4.	$C + CO_2 \rightarrow 2\ CO$	(Boudouard reaction)
5.	$C + 2\ H_2 \rightarrow CH_4$	(Methane reaction)

Depending on the fuel type, the temperature and the amount of air that is supplied different ratios of each reaction is produced. Given this, these reactions will always stay in equilibrium with each other. Looking at the enthalpies of each molecule in table 4.1.1 the energy demand for each reaction can be determined. Within this table the values are given at a temperature of 298 K and a pressure of 1 bar.

Molecule	Enthalpy (kJ/mol)
O_2	0
CO	-100.525
CO_2	393.509
H_2	0
H_20 (l)	285.830
H_20 (g)	-241.818
CH_4	-74.87

Table 4.1.1: Enthalpy of molecules

A positive value indicates endothermic reaction which means that energy is required. A negative value indicates exothermic reaction which means that energy is provided. Using Hess's law, the enthalpy change ΔH for each reaction can be determined giving the following reactions:

	Reaction	**Energy, ΔH (kJ)**
1.	C (0) + O_2 (0) → CO_2 (-393.5) + 393.5 kJ	-393.5 (exothermic)
2.	C (0) + H_2O (-285.8) + 185.3 kJ → CO (-100.5) + H_2 (0)	185.3 (endothermic)
3.	CO (-100.5) + H_2O (-285.8) → CO_2 (-393.5) + H_2 (0) + 7.2 kJ	-7.2 (exothermic)
4.	C (0) + CO_2 (-393.5) + 192.5 kJ → 2 CO (-201.0)	192.5 (endothermic)
5.	C (0) + 2 H_2 (0) → CH_4 (-74.9) + 74.9 kJ	- 74.9 (exothermic)

These reactions clearly show that the oxygen that is provided by the primary air is consumed by the first reaction. The energy (in the form of heat) that is provided by this reaction is partly used by the other endothermic and in smaller amounts exothermic reaction.

Temperature

Furthermore, these reactions show the importance of a high temperature inside the MPF. As mentioned before, higher temperatures create better quality syngas meaning that the endothermic reactions benefit which create more combustible gases like carbon monoxide and hydrogen. At the same time where endothermic reactions benefit, the exothermic reactions decrease. This results in a lower production of CO_2 and methane (CH_4). While reducing the amount of CO_2 is a desired effect, the methane reduction is unwanted. The temperature of the reactor can be increased with proper insulation.

Moisture
Moisture within the biomass fuel has great effect on the outcome gases. Due to more energy that is needed for reaction 2 and 3 less energy remains for reaction 4 which results in a lower production of CO. In the worst cases when the temperature is to low or the moisture content is too high, the water (H20) is not transformed to CO and H2. In this case the water molecule remains and transforms from liquid to gas.

4.4.6 Effects of too much oxygen
High temperature benefits the combustion reaction, therefore one might think adding as much oxygen as possible through the primary air would benefit the process. However, when too much oxygen is added, it can result in lower quality syngas as carbon monoxide and hydrogen are being burned by excess oxygen. This can be seen in the following chemical equations:

Reaction

6. $2\,CO + O_2 \rightarrow 2\,CO_2$	(Carbon monoxide combustion reaction)
7. $2H_2 + O_2 \rightarrow 2\,H_2O$	(Hydrogen combustion reaction)

Ideally these gases should react with oxygen outside the gasifier on top of the burner. When these gases are created inside the efficiency goes down as the energy is given to the heating of the stove. Therefore, the goal is to start these reactions very close to the pot. Looking at the molecular enthalpies the energy of the gas can be determined:

Reaction	Energy, ΔH (kJ)
6. $2\,CO\,(-201.0) + O_2\,(0) \rightarrow 2\,CO_2\,(-787.0) + 586.0$ kJ	-586.0 (exothermic)
7. $2\,H_2\,(0) + O_2\,(0) \rightarrow 2\,H_2O\,(-483.6) + 483.6$ kJ	-483.6 (exothermic)

4.2 STOVE PERFORMANCE MEASUREMENT

This chapter describes how the performance of cookstoves is labeled on an international scale. This labels the different stoves in the market and make them comparable to each other. For this reason, it is important to know how this scale is set up and how important it would be to have a high score.

4.2.1 Introduction

Over the past few years many cookstove programs and enterprises have worked to achieve adoption of high performing cookstove for nearly 3 billion people who rely on solid biomass fuels to meet their primary household energy demands. For this reason, the performance standards and guidelines have been developed.

The performance of cookstoves can be measured and rated according to a five performance tiers scale. These tiers are defined by multiple indicators related to efficiency, emissions, indoor emissions, and safety across five performance tiers.

4.2.2 Tier explanation

Stoves can have different tier ratings for different subjects. For example, a stove can have a tier 3 rating for efficiency while it has a tier 4 rating on safety. Appendix E.1 and E.2 shows the different values of the tier scale.

In general, the following is stated by the World Health Organization:

- Stoves that meet the tier 2 efficiency standard or higher are be counted as efficient.
- Stoves that meet the tier 3 standard for indoor emissions or higher will be counted as clean for health impacts.
- Stoves that meet the tier 3 standard for overall emissions will be counted as clean for environmental impacts.
- Stoves that meet tier 4 are always the highest performing and most likely to achieve the greatest health or environmental benefits.

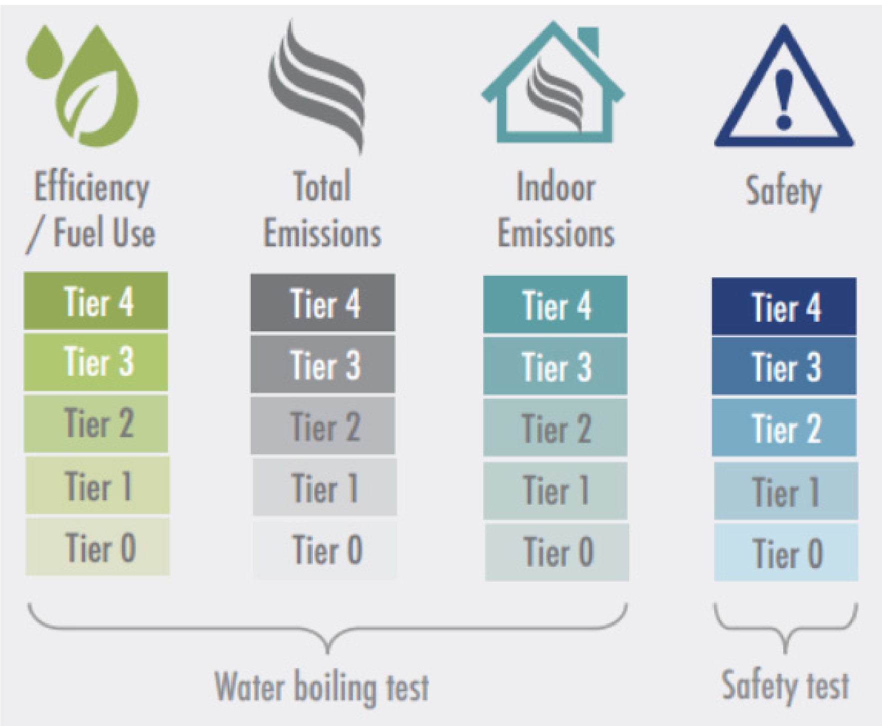


Figure 4.2.1: 5 point tier scale on four different subjects of stove assessment.

4.3 SNV TESTING REPORT

This paragraph will review a performance testing report provided by CCS on one of their previous prototypes. The report has been written by an external party called SNV Laos. Here they have specialized measuring equipment and was set up under the improved cookstove program.

4.3.1 Introduction

An older version of the CCS gasifier (2014) has been tested by SNV to measure its performance on different Tier scales. An extensive report on these results has been written, where multiple tests were executed following the *"WBT protocol 4.2.3"*. It is important to understand how measurements were executed in order to have a better understanding on what is meant by terms such as 'efficiency' and to give an idea on where the current version of the CCS prototype stands. Also similar test could be used in the end for evaluating the new prototype.

This model was a 2014 version, but a similar report on the latest version has never been made. However, data from this report can be used for benchmarking new and improved designs and prototypes.

Image 4.3.1: 2014 version prototype tested by SNV

4.3.2 CCS gasifier 2014 description

This stove is a wood pellet micro gasifier stove that operates with an axial fan and only has forced primary air. This means that additional secondary air is added by natural draft and tertiary air from the environment. The secondary air comes from the holes at the side as well as the bottom where the stove is lifted by the feet. The burner of this design captures the secondary air stream from the side and concentrates the flame in the center.

Dimensions of the gasifier

- Stove length 30 cm with a diameter of 15.8 cm
- Reactor length 21.5 cm with a diameter of 10 cm
- Secondary air diameter 11,7 cm
- Thermal insulation with wool of 2 cm

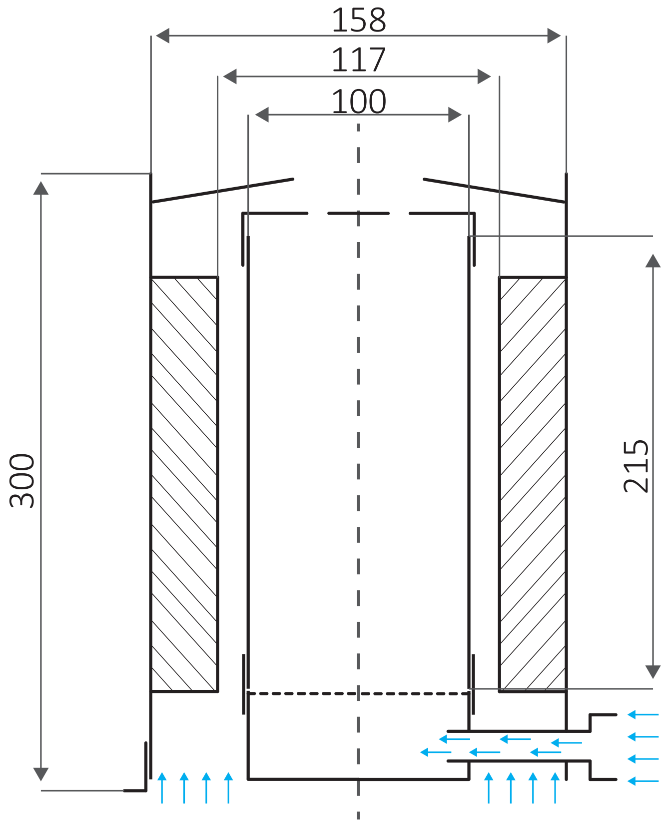


Image 4.3.2: Main measurements of the 2014 stove

4.3.3 Method of testing

The stove was subject to a water boiling test described in the WBT4.2.3 protocol. This test was an effort of the Global Alliance for Clean Cookstoves in trying to have a standardized testing method to make benchmark evaluation and comparison between different stoves possible. The basic steps of this test is visualized in the graph below. There are three steps within this experiment which will be described shortly.

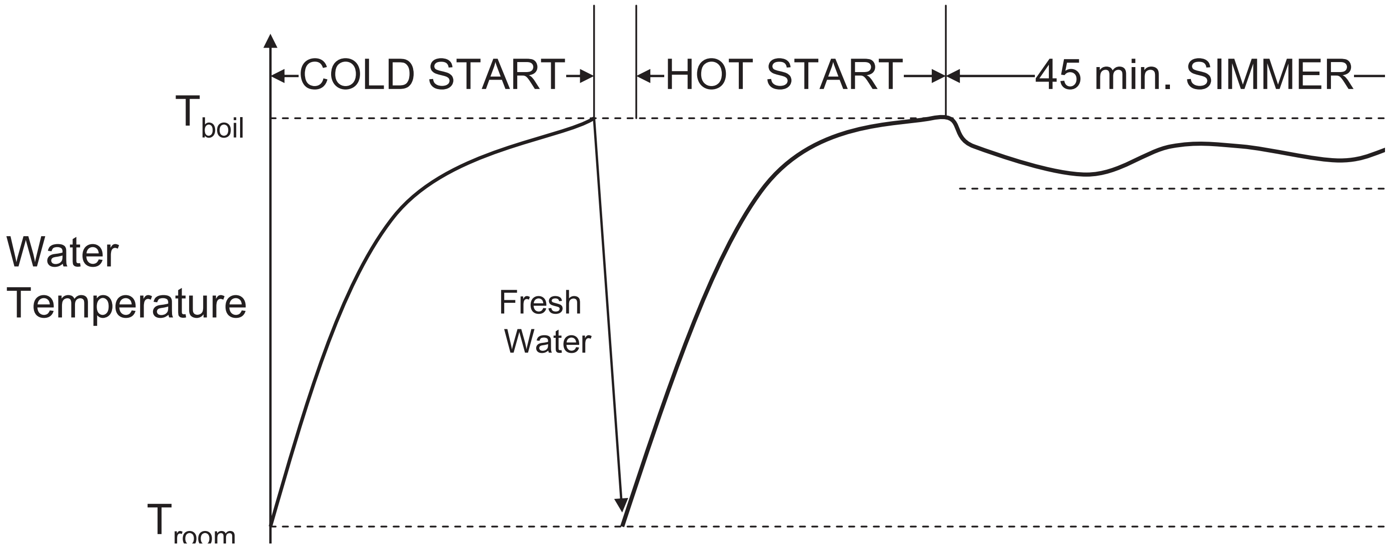


Image 4.3.3: Water boiling test procedure

Cold start

During the cold start, a measured quantity of water at room temperature is heated to its boiling point. 5-liters is the recommended amount but can be altered, if necessary. They call this a cold start since the entire gasifier is cold (room temperature). The cold start starts after just 5-7 minutes when the burner is placed on top of the stove and the pot shortly after.

Steps:

Set the pots on the stove with 5000g of water with the temperature sensor suspended in the water of the pot.

Record

Starting weight of pots with water
Starting water temperatures
Initial mass of the bundle of fuel

Start time when lighting the fire
Start time when pot is placed on top

Hot start

For the hot start a second batch of fuel is prepared and ignited. The difference between the cold start is, that some stoves remain hot for a some time after a first operation is completed. This can influence the results as thermal energy captured in the metal and insulation layers can improve the thermal efficiency. The higher the temperature in the reactor the better the quality of the syngas that is being produced. After placing the burner a fresh amount of water is boiled. The time to boil is measured from this point.

Steps:

Start stove and wait for the gasification process to start. After which put on a fresh pot with 5000g of water.

Record

Starting weight of pots with water
Starting water temperature
Initial mass of the bundle of fuel

Start time when lighting the fire
Start time when pot is placed on top

Simmer test

For the third batch that will be loaded the gasifier is let simmering for 45 minutes. This means that the fan is turned down to decrease the amount of primary- and secondary-air having a lower fuel consumption and a less powerful flame. During this test a pot with 5 liters of water should be kept at a temperature above 94 degrees Celsius.

Phase	Cold start	Hot start	Simmer
Task	Bring to boil temp; 5L in first pot	Bring to boil temp; fresh 5L in first pot	Simmer remaining 5L for 45 minutes above 94 degrees C
Record	Time Fuel Water Charcoal	Time Fuel Water *Assume same charcoal as cold start	Time Fuel Water Charcoal

Table 4.3.1: Water boiling test procedure

Material for testing

For testing the following supplies are needed besides the emission measuring equipment:

- Scale
- Temperature sensor
- Fixture for suspending temperature sensor
- Wood moisture meter or oven
- Stopwatch
- Pot standard that can hold 5 liters
- Heat resistant pad for scale
- Something to unload the char
- Char tray
- Heat resistant gloves
- Water room temp, at least 10 liters
- Wood pellet fuel enough for six batches

Emission testing
- CO sensor
- Sensor for particulate matter, PM2.5

The final design will be tested according to the WBT procedure described in version 4.2.3 of the water boiling test protocol. See appendix J1 for the report of the new gasifier design developed during this project.

5 EXPLORATORY STUDY

5.1 INTRODUCTION

This chapter gives an overview of all the research that has been conducted regarding the user context. The chapter is divided into five topics:

- Cooking traditions in Vietnam (5.2)
- Stove types in the Vietnamese market (5.3)
- Improved cookstoves in the international market (5.4)
- Types of biomass fuel (5.5)
- Processed biomass fuel (5.6)
- Market breakdown (5.7)

This chapter ends by formulating a design focus (5.8). This will be based on identified primary and secondary user needs. It will present the areas that need to be improved of the gasifier, in order to make it ready for the consumer and mass production.

5.2 COOKING TRADITIONS IN VIETNAM

5.2.1 Introduction Vietnam Cooking traditions

This chapter will explore the different cooking traditions, methods and stoves in the Vietnamese market. Results from this study should provide information about the context and will quantify performance parameters such as the operating time of the stove.

5.2.2 Cooking traditions in Vietnam

Due to Vietnam its unique history and lengthy geographical region, the cuisine is very diverse. The Vietnamese cuisine is based on fresh ingredients that are mostly purchased every day in local markets. Meals are rich in flavor and have a great presence of herbs and spices. Depending on the region in Vietnam food taste and preferences change, though cooking style stays similar throughout the country. In appendix F.1 different typical northern dishes have been analyzed. Typical meals for families consist of the following dishes:

- Plain rice
- 2 meat or fish dishes (boiled, grilled, steamed and or fried meat or fish)
- One vegetable dish (cooked or steamed)
- Soup
- Dipping sauces

Cooking times are dependent on the size of the family, and the complexity of the dish. On average it takes about 45 minutes to prepare the meal.

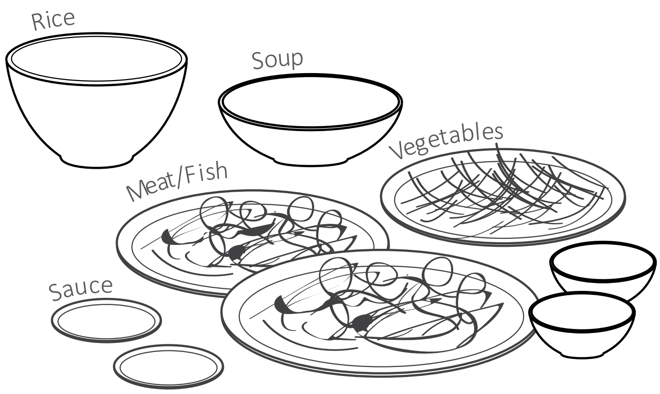


Image 5.2.1: Typical family dish in Vietnam

Statistics

Statistics show that people in both urban and rural areas mainly cook indoors in a separate building. More interesting is that 32.3% of the 736 kitchens that were observed by SNV (SNV,2011) have a chimney. The lowest number of people having a chimney for air ventilation is among the ethnic minorities and the poor with 20% and 18.55% respectively.

Other statistics show that the wife is the main cook of the family. Depending on the family income they are more likely to cook using clean alternatives such as LPG compared to solid fuel use. The report of SNV also reveals that people are likely to switch towards LPG when they make more then $50/ month.

Appendix F.1 also gives a more elaborate overview of Vietnamese cooking statistics.

5.3 STOVE TYPES IN THE VIETNAMESE MARKET

5.3.1 Introduction Vietnam stove market analysis

There are many different stoves in the market each with their own function for different cooking purposes. It is most common for households in Vietnam to have more than just one type of cookstove in their possession. Different reasons for people to choose for a specific cookstove in their home are listed below:

- Operating cost of the stove
- Operating time of the stove
- Time before you can start cooking
- Usability, ease of use
- The type of dish that is being prepared
- Fuel price

All these criteria communicate user needs and are the reason for the many types of stoves. By analyzing these stoves, the user needs and cooking habits can be better understood. This will provide critical information for setting up the list of requirements for the gasifier stove. The most common stoves in the market are:

- Beehive coal stove
- Electric cookstove
- LPG gas stove
- Wood stove/ 3 stone or open fire
- Saw dust stoves

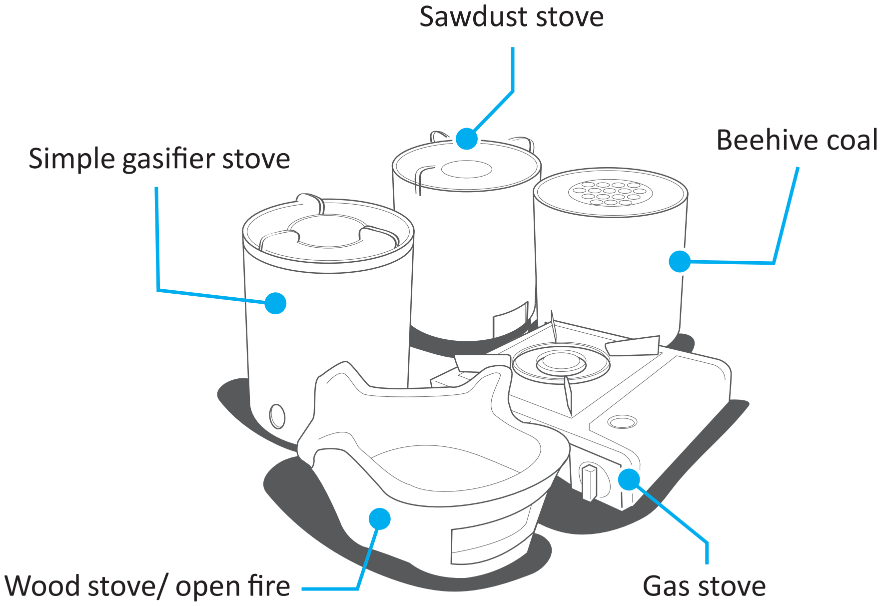


Image 5.3.1: Overview of different stoves in the market

Each stove will be analyzed for its strong points and its drawbacks. Information will be gathered on the following points.

- Time to boil
- Fuel used to cook
- Accessibility of the fuel
- Energy used to cook
- Emissions
- Safety ratings
- Cost to purchase
- Monthly fuel use

5.3.1 summary of Vietnamese stove types

Where would a micro-gasification cookstove fit in the market? In the analysis presented in appendix F.2, it can be seen that multiple cookstoves are used to complement each other. Therefore, the gasifier might fulfill different needs for different users. LPG is the most convenient way for people to cook, and even despite the relative high fuel price it is gaining popularity because it is clean, more comfortable for users, less time consuming and widely available.

The table below summarizes the main advantages and disadvantages of each type of portable cookstove. All the points that are given are from the perspective of the users. It does not account for all groups that firewood is locally available.

A gasifier stove will have its own advantages and disadvantages, for example the availability of the wood pellets, the distribution of the stove, the maintenance or repair if that is needed. All of these factors have to be accounted for when selling the stoves to the different communities.

Portable cookstoves	Advantages	Disadvantages
3 stone fire / Iron-bar cook-stoves	• Cheap and available fuel • Cheap and easy to buy cook-stove	• A lot of smoke • Time consuming and hardship for fuel collection and cooking • Difficult to start, keep and adjust fire • Difficult to keep kitchen clean
Portable cook-stove using biomass	• Cheap (no cost) and available fuel • The price of cook-stove is relatively low (100,000-150,000 VND) • Light and portable	• Produce a lot of smoke • Difficult to keep kitchen clean • Short life span and need to be replaced after 2-3 years • May not be sold locally
Beehive coal stove	• Low fuel cost • The price of the cook-stove is relatively low (100,000-150,000 VND) • Portable • Cleaner than biomass cookstoves	• Produce harmful smoke • Coal may not be sold locally in rural areas • Life span is relatively short, should be replaced after 2-3 years
Saw dust cookstove	• Low fuel cost • Easy to start	• A lot of smoke • Need to be replaced every 2-3 years • Dusty and difficult to keep kitchen clean • Cook-stove may not be sold locally
Portable Electricity and LPG cook-stoves	• Convenient to use • Clean and quick • Easy to keep and adjust fire and heat • Long life span	• High fuel price

Table 5.3.1: Advantages and disadvantages of several portable cookstoves

5.4 IMPROVED STOVES IN THE INTERNATIONAL MARKET

5.4.1 Introduction stove market analysis

As mentioned in the introduction there are already a lot of gasifiers on the market. Looking at these other stoves give a better understanding of general stove design, added functionality, benchmarking and price.

There are multiple ways to classify different cookstoves on the market. The classification that is used in this analysis looks at the type of fuel, the way the fuel is loaded into the gasifier and if it is a batch or continues type of operation. The following stove types exist on the market; the highlighted stoves have been included in the analysis.

1. **Rocket cookstoves**
2. **Forced air stoves**
3. **Natural draft stoves**
4. **Gasifier stoves**
5. Improved charcoal stoves
6. Alcohol cookstoves
7. Biogas cookstoves
8. Electric cookstoves
9. Liquefied petroleum gas cookstoves
10. Solar cookstoves

For this analysis, it is chosen to include only the most popular stoves in the market today. Appendix F.3 gives a clear overview of the different stoves with their characteristics. These include function, price, general dimensions and materials. It has to be mentioned that the data required is not always publicly available. The data that is might not be recent or come from reliable sources, if so it will not be included in the analysis.

A good place to start, is looking at a large online database of cookstoves and their specifications which is available at http://catalog.cleancookstoves.org/stoves. Within this database different filters can be added to search for your criteria. Unfortunately, not every stove that has been developed is also registered at this website or tested on the tier performance scale. When filtering on all the solid biomass fuel stoves, 252 results pop-up. Image 5.4.1 below shows the online database when filtered on the tier performance scale.

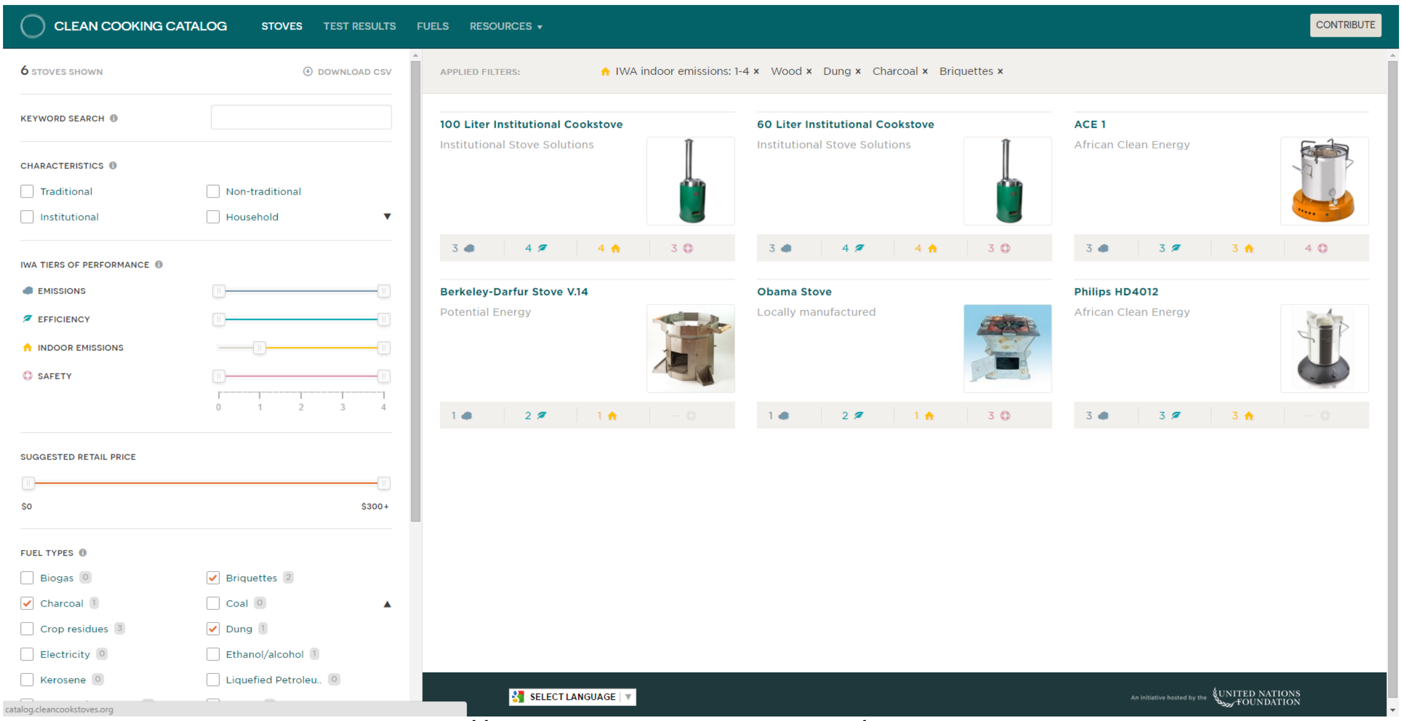


Image 5.4.1: Screen shot from http://catalog.cleancookstoves.org/stoves stove selection

Stove comparison

Some of the stoves that were included in the analysis are illustrated in image 5.4.2 below. Looking at the stoves it can be noted that even though they all have to perform the same function, there are considerable differences. Most of the stoves have the same size as they are all meant to be portable. Comparing the price of these stoves shows a big difference ranging from 10 to 300 dollars. This is greatly dependent on the target market and materials used within the product.

Image 5.4.2: Some of the stoves used in the analysis

5.4.2 Emission and efficiency of stoves in the market

The stoves in this analysis give a clear overview on the different designs and functionality. It is chosen to leave any performance measurements out in this overview and to summarize them in the table below. Looking at the performance there is a great variety regarding efficiency and emission values. Though these values give a good indication of the performance, it has to be noted that these are results from lab tests done by experts. Factors that might influence the performance in practice are:

- Improper usage by consumers.
- Type of fuel used.
- Moisture content of the fuel.
- The pot that is being used (aluminum vs. stainless steel already makes a difference).

Looking at the table below it can be said that forced draft shows a clear improvement on thermal efficiency. Reason for this is that the additional oxygen will improve the thermo-chemical processes. The following statements can be made regarding these results:

- A natural-draft TLUD stove can have high thermal efficiency when processed fuel is used.
- Some forced-draft (fan) stoves have very low emissions, but not all fan stoves.
- Mimi moto stove has the best results among all stoves.
- Some rocket stove designs perform less good compared to TLUD stoves, but not all.

Model	Stove type	Manufacturer	Thermal efficiency	IWA high power CO g/MJ-del	IWA high power PM mg/MJ-del	IWA low power CO g/MJ-del	IWA low power PM mg/MJ-del
Ace 1 cookstove	Forced draft	African Clean Energy	41.5%	0.82	101.1	0.019	0.84
Philips HD4012	Forced draft	African Clean Energy	39.4%	0.978	62.3	0.012	0.553
Mimi moto stove	Forced draft	Mimi moto	46.8%	0.154	13.94	0.007	0.11
Oorja pellet stove	Forced draft	First Energy	37.26%	1.884	74.7	0.024	1.21
Biolite basecamp	Forced draft	BioLite	-				
Biolite camp stove	Forced draft	Biolite	-				
Envirofit M5000	Natural draft	Envirofit	38.8%	2.26	429.2	0.04	0.726
Envirofit G3300	Natural draft	Envirofit	39.4 %	3.1	249.5	0.043	0.357
Paul oliver stove	Forced draft		-				
Champion stove	Natural draft		-				
Awamu quad stove	Natural draft	Awamu Biomass Energy Ltd (ABE)	33%				
Awamu troika	Natural draft	Awamu Biomass Energy Ltd (ABE)	-				
Mayon turbo stove	Natural draft	REAP-Canada	28.8 %	12.95	443.0	0.137	7.52
Instove	Forced draft	Institutional Stove Solutions	46.7 %	1.3	102.0	0.008	0.5
Solar serve 3G clean cook-stove	Natural draft	Solarserve	-				
Philips Natural Draft Stove HD4008	Natural draft	Philips	34.6 %	5.16	485.0	0.038	2.607
TERI SPT_0610	Forced draft	RBS Group	36.84%	2.24	147.39		
Prime cylindrical biomass stove	Natural draft		-				
Berkeley-Darfur stove	Natural draft	Potential Energy	37.4 %	5.175	276.5	0.075	3.367
Rocket works stove	Natural draft	Rocket Works	44.8 %	2.23	76.0		
Berkeley-Darfur Stove "Cool Mesh"	Natural draft	Potential Energy	-				
Greenway Smart Stove	Natural draft	Greenway	24.1%				
Shengzhou Top Load Fan Stove	Forced draft	Shengzhou	47.11 %	1.76	47.198	0.012	0.47

Table 5.4.1: Different models of improved cookstoves with their test results

5.4.3 Conclusion market analysis

This market analysis shows 24 different stoves which have all been produced and/ or developed in different geographic locations all over the world. Only two of them, the stove from solar serve and Paul Oliviers gasifiers, are specifically focusing on the Vietnamese market and will be produced in the middle and south of Vietnam. The solar serve stove is a rocket based stove, the advantage is that rocket stoves are more suitable for different kinds of fuel but have a lower performance.

Price

Looking at the price of the different gasifiers they range from only $10 to $300 (with the exception of the Instove which is a lot more expensive). It can be argued that the more expensive stoves justify their price when looking at their performance. There are other factors that influence the price, such as durability, improved usability or additional features. The gasifier that has the highest success rate in the market is the Oorja pellet stove of which over 400,000 units have been sold, primarily in India and cost only $23. There are multiple alternatives for people to buy a stove if it is too expensive to pay the full amount in one go. Micro financing, micro credit or loans can provide a solution. It is not recommended to donate a stove as people will feel no pride in owning one and will dispose of it easier if they have no personal investment in it.

Aesthetics

Even though all these stove have the same function for users, they are different when looking at the aesthetics. A good reason for this is to differentiate themselves from the other products on the market, another reason could be that cultural differences influence the product its appearance. Because these stoves operate in international markets, cooking equipment will also contribute to the stoves appearance. Not only were these stoves selected for this analysis because they appear in most of the literature that is available, they also stood out because of their appearance. The following factors can add to the aesthetic appearance:

- Differentiate from the “archetype” cylindrical shape
- Material usage
- Surface decoration
- Color contrast of the different parts
- Personalization
- Communicate the function of the product
- Ergonomics

Electronics

One of the major differences between the different stoves is that they are purely mechanical, or they are supported by electronic components. An advantage of leaving any electronic devices out of the stove is that it will decrease the price and it might increase the durability as there are less parts that could break down. The biggest advantage of adding electronics is having forced draft which benefits the performance. It might also add to the usability, for example people who are not connected to the power grid can generate their own electricity to power lights or their personal devices such as phones. The electronic components that are used in the different stoves are:

- Fan (axial and centrifugal)
- Rechargeable batteries
- Thermo-electric generator to charge the internal battery
- Solar panels for charging
- Electric output for charging or using other devices
- Power control of the flame (by regulating the fan speed)

5.5 TYPES OF BIOMASS FUEL

5.5.1 Introduction biomass fuels

Gasification can be applied to many different types of solid biomass fuels, see image 5.5.1 below. Every biomass fuel will burn when enough heat and oxygen is added but as shown in the previous analysis most stoves are optimized for a specific type of fuel. There are many reasons for focusing on a specific type of fuel when developing a stove. They can be reasoned from the technical-, and user perceptive.

Image 5.5.1: Different biomass fuels

Technical aspects regarding fuel choice to achieve optimal fuel use and combustion efficiency. The solid biomass fuel should:

1. Be dry, with a moisture content preferably below 10 %. High moisture content results in difficulties with the operating the stove and decrease the available energy output of the fuel. This is because more energy is needed to evaporate the moisture.
2. Be slightly chunky to allow for air/gas to flow through the fuel. For finer fuel types such as sawdust and rice husk it is advisable to use a fan-powered micro-gasifier with forced primary air for enhancement and control of the airflow.
3. Have particle shapes that enable convenient loading of fuel into the reactor. This includes easy stacking and the ability to easily load fuel chunks into the reactor.
4. Have relatively uniform particle size distribution to avoid compacted zones or oversized voids within the fuel container that could prevent the uniform progression of the pyrolytic front through the fuel-bed.
5. Have sufficient energy density in order to balance the heat output of the burnable mass (inside a given fuel-container volume) with cooking duration and refueling efforts. This also allows the gasifier to be smaller and cheaper without compromising the cooking time of the stove.

User aspects regarding the choice of solid biomass fuels are listed below:

- Fuel must be economically available in the long and short term.
- Fuel distribution can create business opportunities for people.
- Fast-growing fuels should not negatively impact the biodiversity of the locality or compete with resources necessary for food production.
- The fuel should not contain or release any toxic or harmful substances. Some fuels may have been treated with toxic substances for a previous use and can therefore be harmful when combusted. An example would be lumber for insect and rot resistance. Such treated materials should be avoided, especially in cooking applications in which humans are in close proximity of the combustion gases.

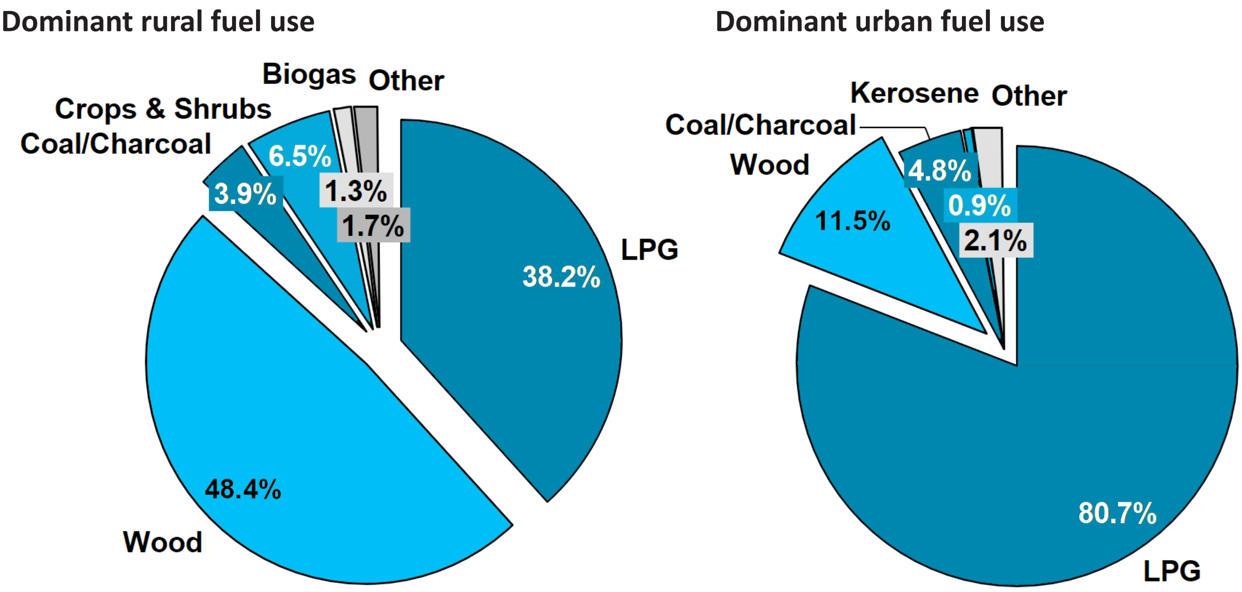
5.5.2 Biomass fuels in Vietnam

Vietnam its wood and furniture industry had a massive growth in the past few years and became the second largest exporter of woodworks in Southeast Asia. (Pelletmillvietnam.com) As a byproduct of this industry almost 2 million tons of sawdust is created each year. This could be used for pellet production as it does not require additional preprocessing such as grinding. After processing it can be sold as fuel for 250-400 VND/kg. In Vietnam the main varieties of tree are Acacia, Pine, rubber tree, Cajupu, Eucalyptus and some other tropical woods.

The main agricultural residues in Vietnam consist of rice straw, corn leaves and cobs. The industrial byproducts consist of rice husk, bagasse (from sugar cane) and coffee husk. As the second largest rice export country in the world, the biomass that can be used as fuel is huge. However, because rice production is only in certain months a year the rice husk prices fluctuate. During the main season from January to April, the price ranges from 30-40 VND/kg. From August to September this price is increased to 50-100 VND/kg. The same as with sawdust, rice husk does not require any preprocessing before making pellets out of it.

Fuel usage rural vs. urban

Looking at the fuel usage in the rural and urban area in graph 5.5.1 it confirms the assumption that people in the rural area rely more on solid biomass as a fuel than in the cities. It can be assumed that this is due to the availability of the fuel in that area, as well as the price of more expensive fuel types such as LPG.



Graph 5.5.1: Dominant fuel use in rural and urban areas in Vietnam

Advantages and disadvantages agricultural residues

Looking at the technical and user aspects, there are both advantages and disadvantages to using agricultural residues as fuel. In table 5.5.1 below these points are summarized.

Advantages	Disadvantages
• Agricultural residues are often freely available for rural families such as farmers. • Controlled burning in a stove is cleaner and more environmentally friendly than uncontrolled burning. • The char that is left over after the combustion can be taken back to the field and used as plant nutrient. • Low impact on women's time for harvesting • Agricultural wastes are often easier to light than wood and charcoal. • Generally, requires less time for preparation than wood burning.	• When burnt in open fires or traditional improved stoves, residues can cause extreme air pollution, but they do burn well in gasifier stoves. • They can be bulky and have to be carried to the homes. • Storage can require more space inside a house or shelter when the bulk density is low. • The seasonal availability of crop residues can limit their continuous use throughout the year. • The burning time is often shorter due to their lower calorific values and bulk density.

Table 5.5.1: Advantages and disadvantages of using agricultural residues as fuel

5.5.3 Energy content of different fuel types

An important difference between various fuel types lies in the gross calorific values. This value gives the best indication of the energy content within a specific fuel type. The table below shows the gross calorific values of different processed and unprocessed agricultural residues and wood. The main reason for a lower calorific value of rice straw and rice husk is the higher ash content (17–26%) compared to other agricultural biomass fuels (0.3–2.0%). With pelletizing it is possible to increase the calorific value of wet biomass fuels like wood.

Fuel type	Average diameter in (mm)	Bulk density, wet (kg/loose-m3)	Ash content % on dry matter weight	Moisture content % on wet basis	Gross calorific value of dry matter kWh.kg (MJ/kg)
Rice husk	2 - 3	70 - 110	17–26	10 - 12	3.5–3.7 (12.6–13.4)
Rice husk pellet	8 - 10	600	6 - 7	7 - 8	4.78 (17.2)
Forest chips		250 - 300	0.5-2.0	40 - 55	5.1-5.6 (18.5–20.0)
Wood pellets		640 - 690	0.3-0.5	8 - 10	4.4–5.3 (15.8–19.2)
Firewood (Pine)		240 - 320	1,2	20	5.1-5. (18.3-20.0)
Sawdust		250 - 300	0.4-1.1	50–55	5.2–5.3 (18.9–19.2)

Table 5.5.2: comparison of different biomass fuels (1 kWh is 3.6 MJ)

5.6 PROCESSED BIOMASS FUEL

As can be seen in the previous analysis on different fuel types, processed fuel seems to be the most promising for gasifier stoves. This shows that CCS was right to move away from rice husk gasifiers and focus on processed fuel types. It is therefore interesting to investigate just how these pellets are made and what types of biomass waste can be converted into pellets.

Vietnam does not have an established distribution network for pelletized fuel. Unlike other alternatives such as LPG or beehive coal briquettes which are fully established in Vietnam its society. Pellets can currently only be bought in high quantities from suppliers, which do not necessarily have to come from Vietnam. When bought in bulk, wood pellets can be bought for 3500 VND/ Kg. Since there is a lot of agricultural waste available it can be much more valuable to invest in a pelletizer machine within the local communities.

There are different types of pelletizer machines, though they all provide the same functionality they differ in production capacity. The process for making pellets is simple, first the raw material is grained to finer products. Then it is loaded into the pellet mill where a roller forces the raw material into channels where a knife cuts them off to the right length.

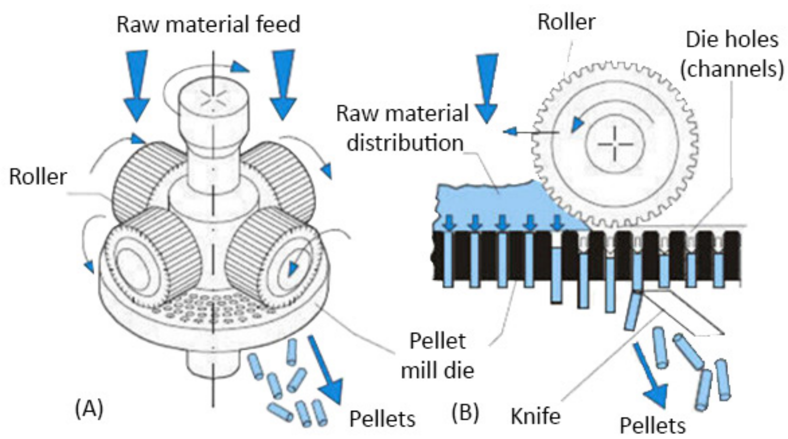


Image 5.6.1: Working principle of a pelletizer machine

Image 5.6.2: Steps for processing biomass to pellets

5.7 MARKET BREAKDOWN

5.7.1 Introduction market segmentation

There are many different market segments on which a gasifier stove could focus. Each of these segments have their own specific needs and demands. A presentation by the global alliance for clean cookstoves showed a Vietnamese market assessment for cookstoves ("Vietnam Market Assessment Sector Mapping", 2012). Within this presentation the following assumptions were made about the Vietnamese market:

- The animal farmers do not exist in the cities and all animal farmers are above the poverty line, due to research indicating that animal farmers have more wealth
- The poorest segments of urbanities use traditional fuels
- Animal farmers using modern fuel can still be converted to other methods

From these assumptions the Vietnamese household population can segmented into four profiles. It is estimated that the potential market for a cookstove intervention in Vietnam is approximately 12.8 million households:

1. *Rural animal farmer*
2. *Inaccessible disadvantaged*
3. *Rural leapfrogger*
4. *Lower income urbanite*

From these segments it is important to know what their current cooking devices are, what barriers they have for switching to a better alternative such as a gasifier and if they are familiar with indoor air pollution.

Other interesting markets on which a gasifier could focus are larger scale applications such as restaurants or street vendors. These will have some different needs compared to household use but will benefit from the lower fuel costs compared to LPG or electricity. Another interesting segment would be the "western market". This includes people who would use the stove for camping or other outdoor activities. Interesting when looking at the business plan behind some of the other stoves like Biolite or Ace1 is that they target people who suffer from indoor air pollution and also the western market. The profit made in this segment is much higher and even helps covering the costs for the stoves that are sold to the development market.

5. *Full service restaurants*
6. *Streetfood vendors*

Within the western market the recreational users can also form an interesting target group. This segment includes the people with more financial recourses and time available. They would be using the stove occasionally for outdoor activities or holidays.

7. *Recreational users*

An overview of the different market segments with their characteristics are given in appendix F.4.

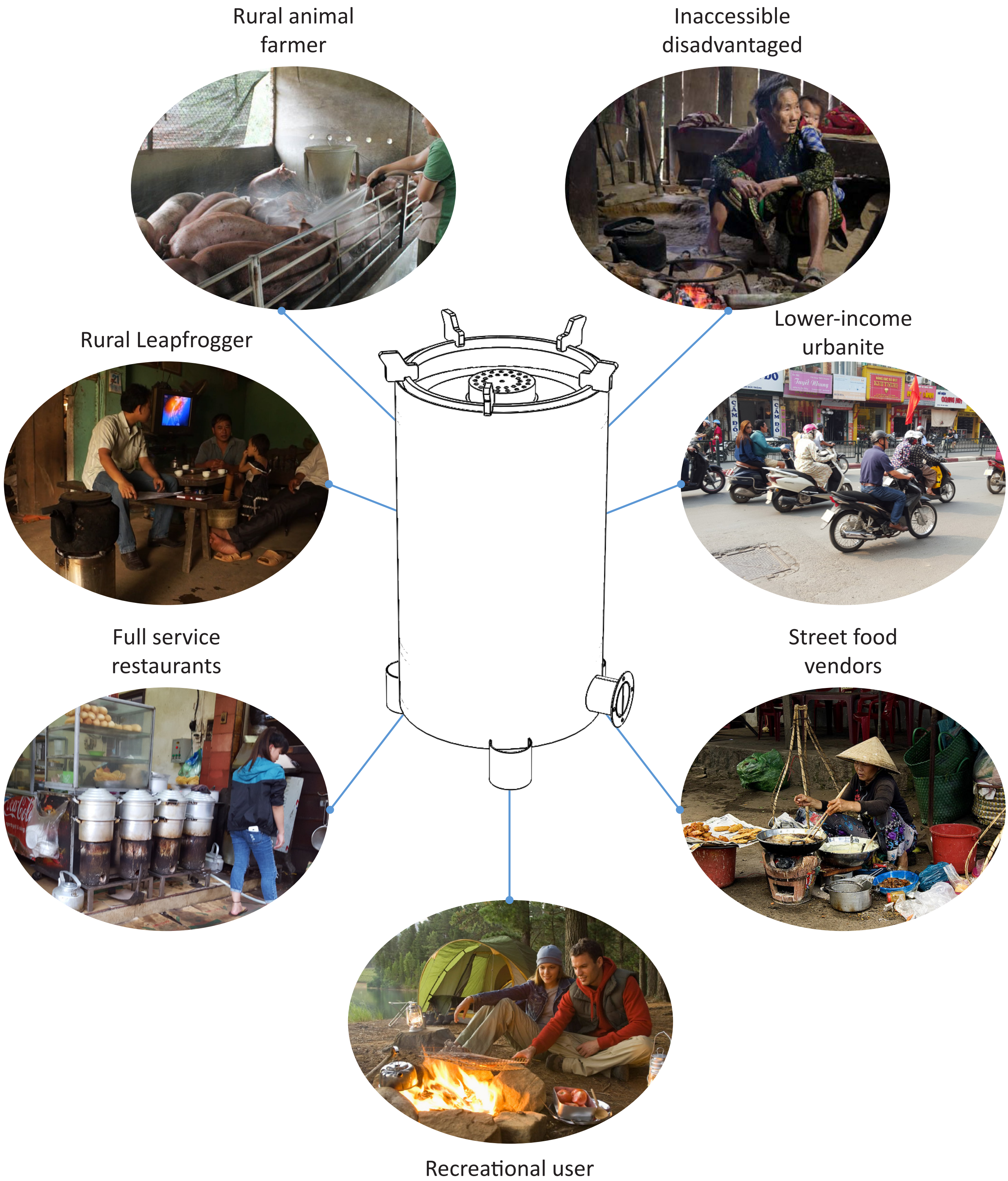


Image 5.7.1: Seven market segments for a gasifier stove

5.7.2 Conclusion market segmentation

In table 5.7.1 below, an overview is given from the characteristics of a gasifier and how important it is for that specific segment. The scale ranges from 1 (not important) to 5 (very important). The following conclusions can be made based on this analysis.

- For segments with low financial recourses initial investment and operational cost should be low
- For segments which use a lot of fuel low operational cost are important as it will increase their fuel savings
- Portability is important for people who have to carry the stove and for people who cook outside in urban areas
- Electricity independence is important for people who use the stove where there is no electricity
- Independence from pellet fuels is important for people who want to use their agricultural residue or biomass collected from around their home.
- Bio-char benefits are only interesting for people who live in rural areas
- Comfort, low maintenance and stove safety are important for all users
- Continues operation is important for segments that use the stove for long periods during the entire day
- Low toxic emission and high efficiency are important characteristics for people that use a gasifier on a daily basis.

	Rural animal farmer	Inaccessible disadvantaged	Rural Leapfroger	Lower income urbanite	Full service restaurants	Street food vendors	Recreational users
Initial investment	4	5	4	4	2	3	1
Low operational cost	4	5	4	4	5	5	1
Portability	2	3	2	3	1	5	5
Electricity independent	2	5	1	1	1	5	5
Independent from pellet fuel	2	3	2	2	1	2	5
Bio-char benefits	2	2	2	1	1	1	1
Durability	4	5	5	5	4	5	4
Status	3	3	3	4	4	4	2
Comfort	4	4	4	4	4	4	4
Low maintenance	4	4	4	4	5	5	4
Stove safety	4	4	4	5	5	4	5
Continues operation	3	3	2	2	5	4	3
Low toxic emissions	4	4	4	4	5	3	2
High efficiency	4	3	4	4	5	5	2

Table 5.7.1: Importance of different characteristics of the gasifier for each segment

5.8 DESIGN FOCUS

From this exploratory study, primary and secondary user needs have been defined (appendix F.6). From this it was determined that the batch operated cookstove does not fulfill the user needs for each segment. It is chosen to investigate the possibility of a continues gasifier, but ultimately focusing on the production of an optimized version of the initial lab prototype of CCS. Therefore, during the last stage of this project, the focus will lie on improving the following parts of the gasifier to make it ready for the consumer and mass production:

- The airflow division
- The burner
- The pot support
- Feet design
- Aesthetics
- Material selection
- Electric control
- Possible add-ons

The list of requirement is documented in appendix F.7 . This will be used as guidelines for ideation during the development phase. Later the design can be evaluated to see in what requirements have been fulfilled or in which area the product is still needs improvement.

Furthermore, as mentioned in the initial analysis in chapter 2.4, challenges go beyond just the design of the stove. The distribution of the product and the fuel is also important for the success in the market. The user should understand what the benefits of purchasing a stove are for them. A lot of stoves that are being sold (or given away) are not used because the stove manufacturers, policymakers or other people who are more accustomed to higher living standards think that traditional ways of cooking is a problem. Regardless of all this, it is ultimately the customers who decides if they want to implement the gasifier stove in their lives. For this stove to succeed the market still has to be convinced of the benefits it has for them.

6 DEVELOPMENT

6.1 INTRODUCTION

During the development phase only the most interesting ideas have been documented. The gasifier can be divided into nine areas. Each section will be explored individually to provide a solution for the presented challenges in the previous chapters.

1. Batch/ continues operation (6.2)
2. Air control valve (6.3)
3. Burner design (6.4)
4. Pot support (6.5)
5. Feet (6.6)
6. Insulation (6.7)
7. Handles (6.8)
8. Electronics (6.9)
9. Body (6.10)

Then there are some other interesting areas which can improve the usability of the stove. Some ideas are developed in this paragraph which can be taken into account when recommendations are given at the end of this project.

10. Add-ons (6.11)

After the ideation phase a final concept will be presented in paragraph 6.12, implementing the most optimal results for each area.

6.2 BATCH VS. CONTINUES OPERATION

Most gasifiers from the market analysis and the gasifiers CCS has already developed are TLUD based, batch operated stoves. However, looking at the market demand a continues operated stove would present more benefits for the user. For this reason, these two directions will be explored further.

Looking at the image on below a schematic overview of the airflow of a batch operated design and a continues feed design is given.

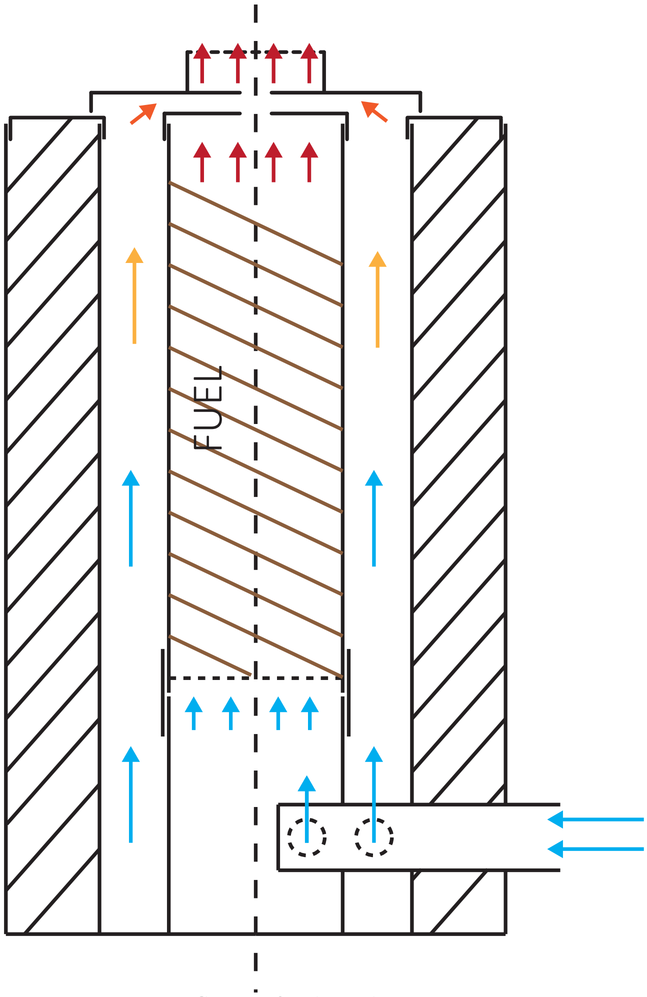


Image 6.2.1: Airflow of a batch operated stove

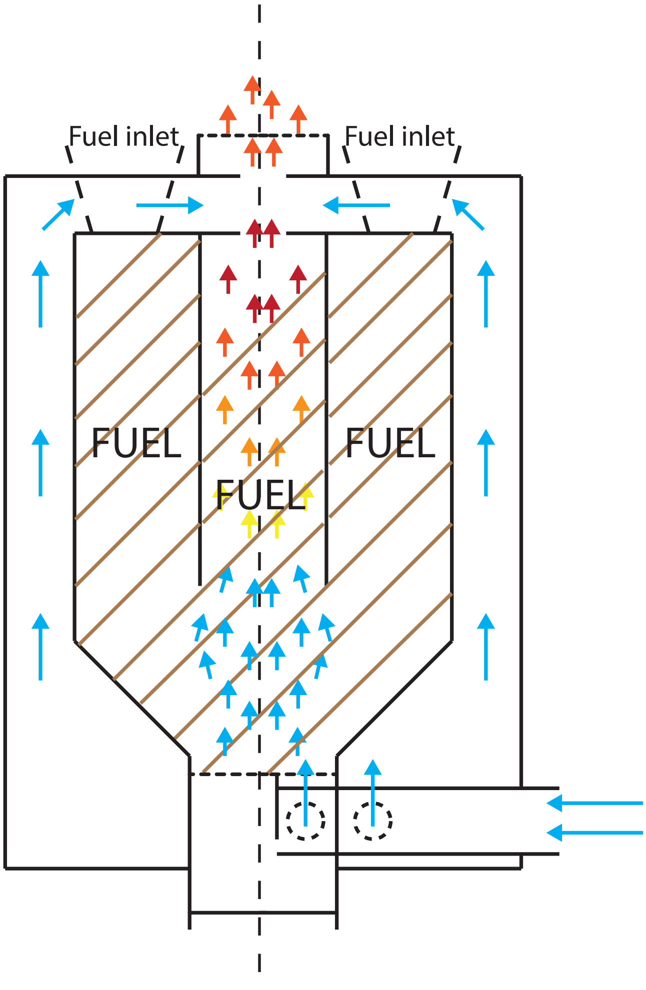


Image 6.2.2: Airflow of a continues operated stove

The batch operated stove works the same way as the old design where the reactor can be taken out of the gasifier and filled with fuel. The secondary air is guided between the insulation layer and the reactor so it heats up when it reaches the top. It also helps cooling down the gasifier after the batch is finished.

The continues operated stove allows the user to add more fuel during the operation, thereby extending the process. In this setup the 'waste' heat from the reactor is used to heat up the fuel, and already vaporizes the moisture from the fuel. The benefit from this setup is that the energy that is lost in the other setup is now used to prepare the fuel when it meets the MPF, which might increase the efficiency. The downside of this setup is that it has not been tested and the secondary air might not be hot enough when it is mixed with the gas on top.

The two principles as described here use many of the same components and can therefore be developed alongside each other. Costs will play an important factor when deciding upon one of these methods.

6.3 AIR CONTROL VALVE

Most of the older stoves in the market rely on natural draft or forced draft for the primary air only. More recent models made the shift to add forced draft secondary air as well but lack in the option to control them independent from each other. This provides the opportunity to control and optimize these two air flows. From testing it is learned that the control of the primary and secondary air ratios can have a significant influence on the performance of the stove. As explained, emissions values are greatly dependent on the amount of oxygen that is added to the combustion process.

Two negative aspects of including a valve are an increase in production and selling price as well as steeper learning curve for the users. Reason for this is that the user has to know when to adjust the primary and secondary air. This make improper use of the gasifier more likely to happen. Therefore, only for testing an improved control valve was developed to determine the right amount of primary and secondary air.

The division of the primary and secondary air can be obtained using several methods. Image 6.3.1 gives a schematic overview of four options:

- The first is using the resistance of the holes in the grade and the burner to divide the primary and secondary air. This method is low cost and is used by stoves such as the Mimi Moto, Philips and Ace 1.
- Option two is to split the air flow directly from the beginning. This gives the user a lot of control and a valve can easily be implemented.
- A third option is suitable for the CCS gasifier as it is currently made. Separate chambers have the advantage to build up a constant pressure for that flow without the interference of each other. A valve can be made to partly cover the holes in the tube, allowing more or less air to enter.
- Option four is to implement a split airflow and chambers. This will provide the advantage that a change in the flow of one channel, will have less of a influence on the other flow compared to option three. This option was used also in the previous prototype of CCS.

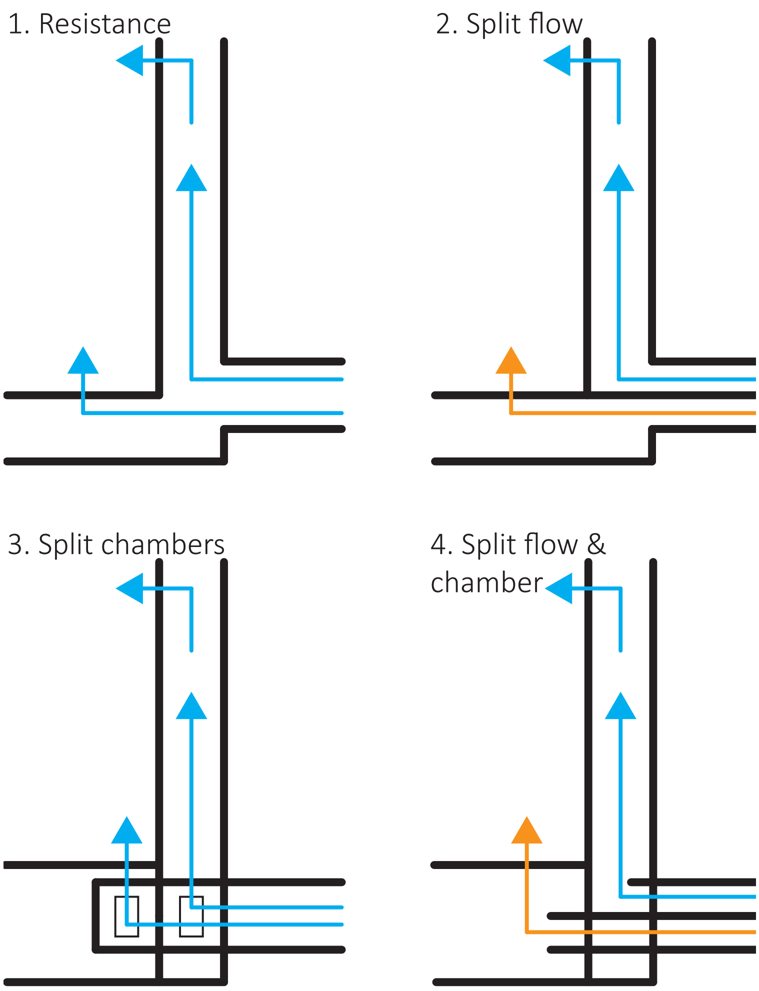


Image 6.3.1: Different airflow configurations

Valve prototype

A prototype of the valve was built with two cylinders that can rotate individually from each other allowing more or less air to flow through the hole.

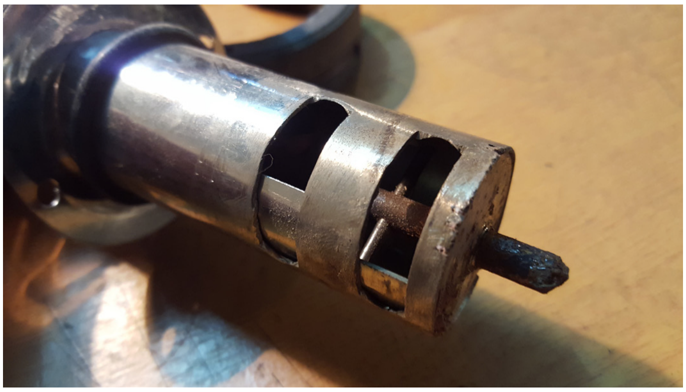


Image 6.3.2: Close-up of the two air slots

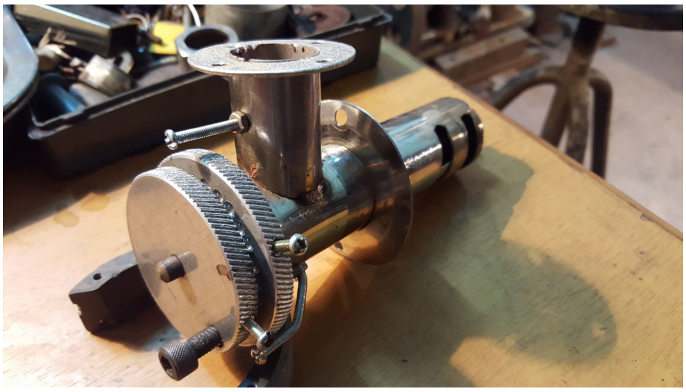
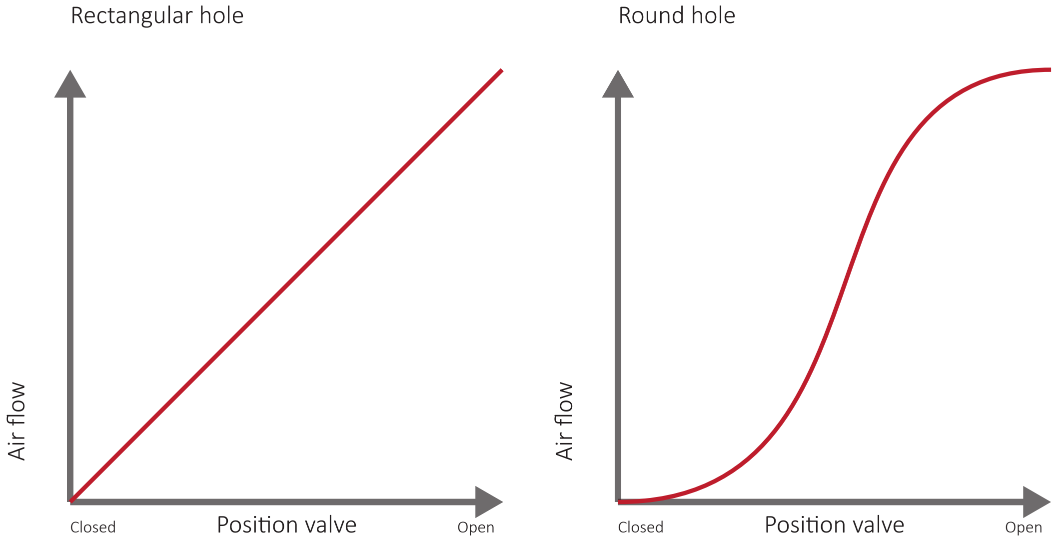


Image 6.3.3: Close up of the airflow division control

The holes in the tube have been made rectangular instead of round. Even though round holes are easier to produce, it would not give a linear correlation between the position of the valve and the air that is allowed to enter. This is visualized in graph 6.3.1 below.



Graph 6.3.1: Rectangular vs. round hole

6.4 BURNER DESIGN

Multiple burners have been developed during this project according to the same methodology.

First the old burner was analyzed and tested. Different positive and negative points were summarized and an idea was developed to make an improvement for a new version.

The second step was to build a physical prototype so that the idea could be tested. Different measurements such as observations and performance (boiling water primarily) were made.

The third step was to use this data, from which a new idea was developed to make another iteration reaching for an optimal design.

The key objective is to develop a burner which mixes the primary and secondary air in such a way, that it produces a clean combustion for different turn down ratios. The flame should also be burning on top of the burner ports preventing it from self-destructing the material and increasing the efficiency. The final results has been given in image 6.4.1 on the right.

The development process of the burner design is documented in appendix G.1. A total of 5 different burners were made besides the one from the latest presented prototype of CCS.

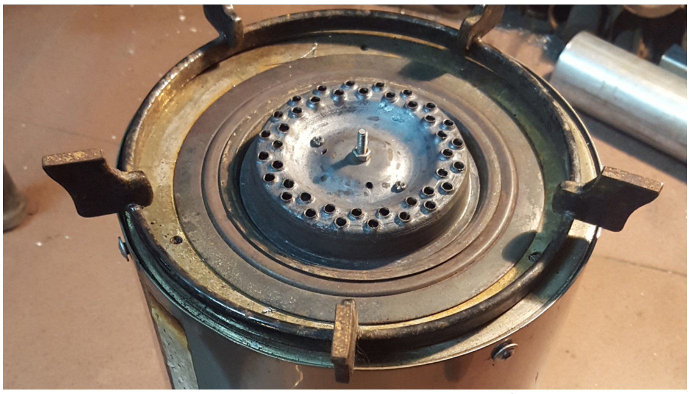


Image 6.4.1: Burner placed on the gasifier

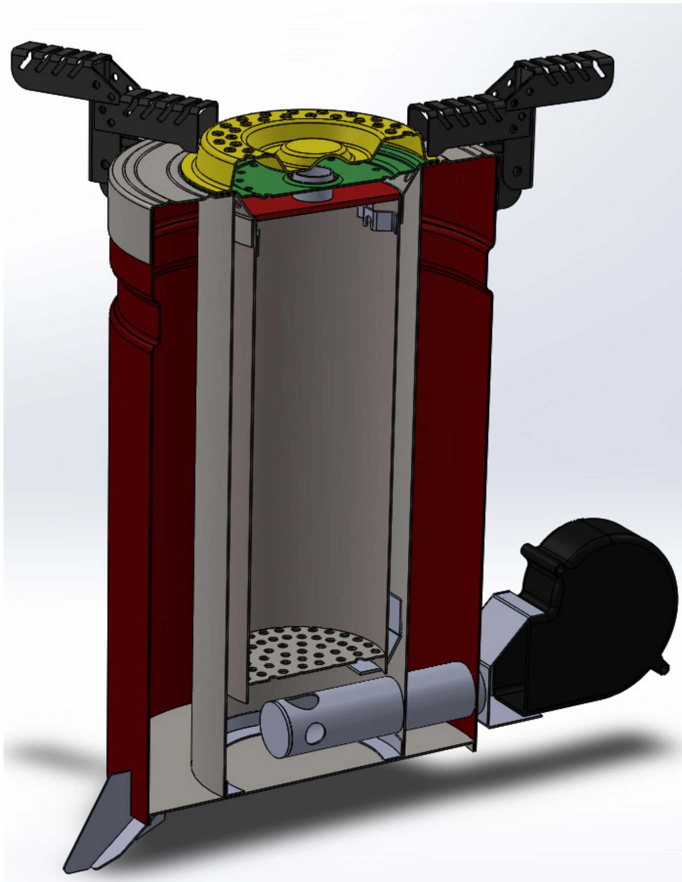


Image 6.4.2: Cut view of the total gasifier with new burner and air division tube

Final results

The final burner design succeeded in solving the presented problems. By optimizing the air flow and decreasing the turbulence inside the burner the flame is now burning on top of the burner ports. The flame appears to have a clean combustion as the flame is almost entirely blue. The yellow tips do indicated that particulate matter is being emitted as they radiate due to the high temperatures.

The turn-down ratio seem to be working successful as well. During several tests the intensity of the fan was decreased which decreased the strength of the flame and lowered the fuel consumption.

The size of the burner is good enough for smaller pots as the flame is not escaping from around the sides of the pot.

Image 6.4.3: Produced flame burning on top of the burner ports

Image 6.4.4: Burner 3 with pot placed on top

6.5 POT SUPPORT

The pot support that is currently used in the prototype is a stock part that can be bought from other manufactures. However, designing your own gives the advantage to make a better fit to the stove its design. Based on the design parameters some ideas of the pot support can be developed. It is likely that the pot support will be sticking out as they should facilitate pots that are bigger than the gasifier itself. Therefore, the pot support should:

- Support big and smaller cooking equipment
- Support the pots on the most efficient distance from the flame
- Be detachable or collapsible for packaging and transportation
- Be simple to install by the user
- Have alignment features to distribute the pot support evenly
- Be robust and provide good stability
- Be low cost
- Improve the aesthetics of the product
- Not have any sharp edges

Four ideas have been explored that are commonly used in stoves (See appendix G.2 for more detail). Each idea will be assessed on the criteria presented:

Image 6.5.1: Idea 1 removable plate

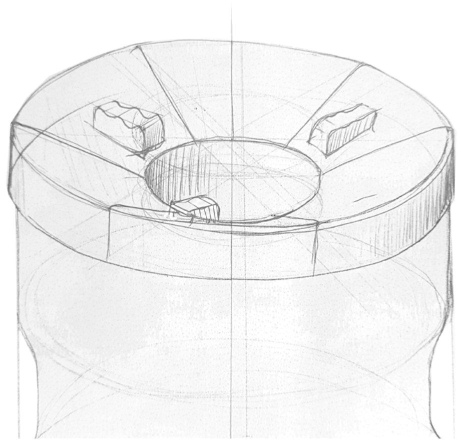


Image 6.5.2: Idea 2 cast iron support

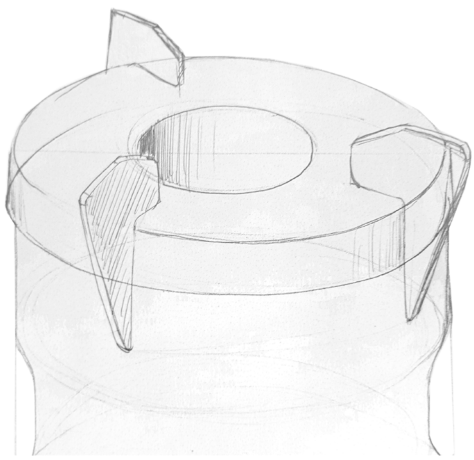


Image 6.5.3: Idea 3 sheet metal support

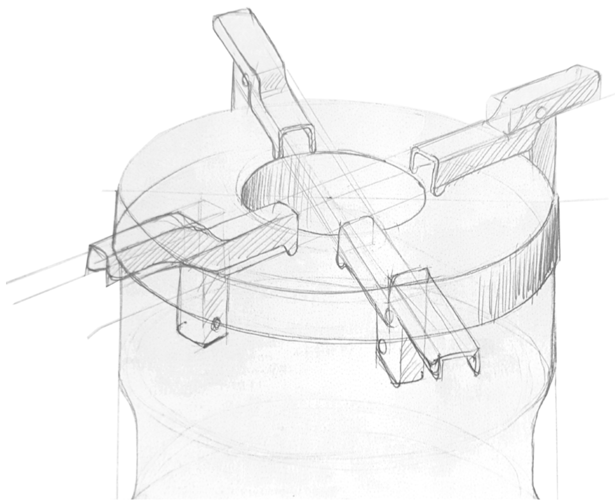


Image 6.5.4: Idea 4 collapsible support

Idea 1 removable plate

The first idea is based on the same principle as a lot of portable gas burners. The support can be flipped upside down to store it during transportation. Other options for this support is to integrate the funnel into the support. This way the component becomes more modular and can easily be replaced when it has a defect. Looking at the criteria there are two concerns, the first is that the additional ring adds to the cost. Another negative aspect is that big pots might not get proper support, as the size is limited to the size of the body.

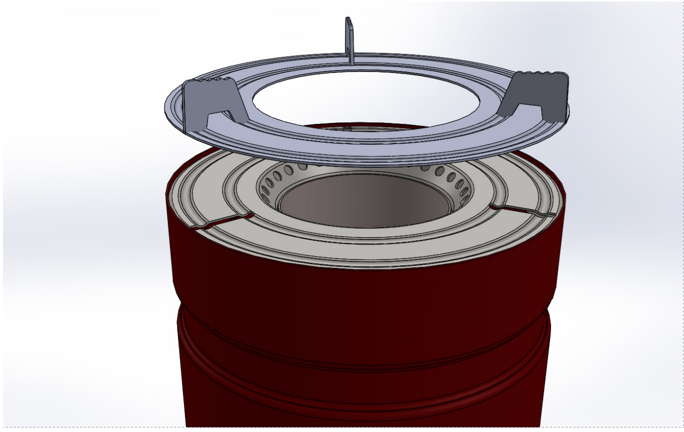


Image 6.5.5: Idea 1 removable plate

Idea 2 cast iron support

The second idea is to cast the entire top plate with the secondary air holes in the funnel and the pot support in one component. An incline in the support can both reflect heat back to the pot and protect the flames from wind. Cast iron has a good resistance to high temperatures but is costlier to produce compared to a sheet metal solution. It should be investigated if the higher costs are profitable for the consumer in the long run. Another negative aspect is that big pots might not get supported properly due to the limited size.

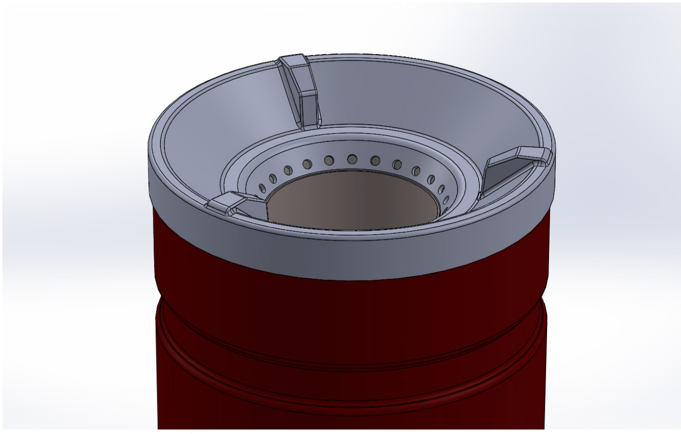


Image 6.5.6: Idea 2 cast iron support

Idea 3 sheet metal support

The third idea is to use three sheet metal pieces that are snapped onto the gasifier. Due to the low investment costs for tooling and material use, it provides the cheapest option of the ideas that are presented here.

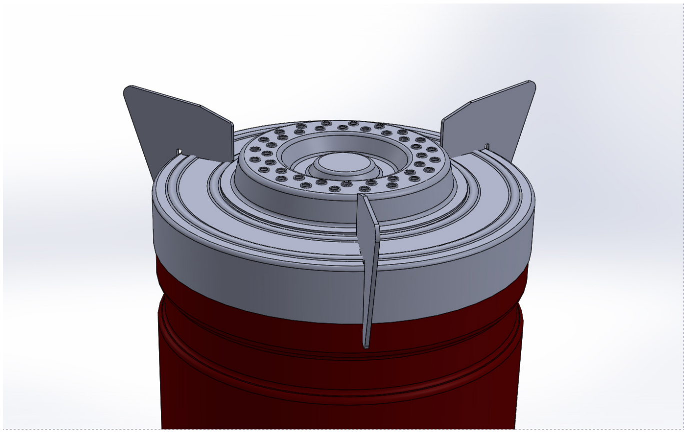


Image 6.5.7: Idea 3 sheet metal support

Idea 4 collapsible support

The fourth idea is to make the support collapsible to facilitate small and bigger pots. It is chosen to have four support points. Reason for this is that the support can then be used as handles for when you want to move the gasifier. Due to the complexity of the components this option adds to the costs compared to the third idea. However, it does include an additional function.

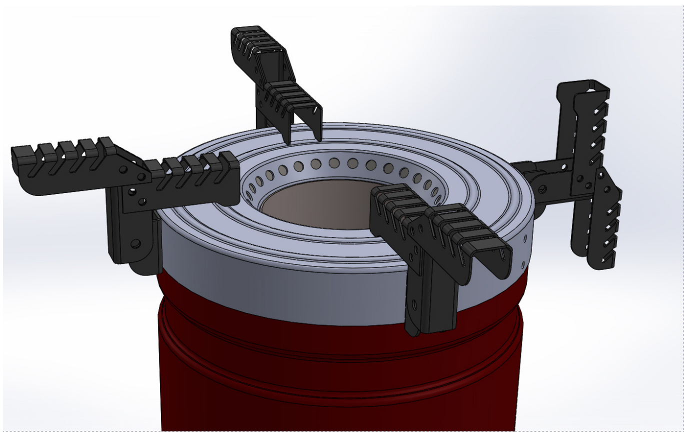


Image 6.5.8: Idea 4 collapsible support

6.6 FEET

For the feet several design directions were explored. The most important function of the feet is to provide stability of the gasifier while cooking. Through testing it was also determined that the bottom of the gasifier becomes very hot near the end of the batch operation. If the gasifier is not lifted off of the ground, it could damage the surface it is standing on. Similar to the pot support, the feet components stick out. Therefore, besides providing these two main functions, the feet should:

- Be robust and provide good stability
- Be detachable or collapsible for packaging and transportation
- Be simple to install by the user
- Be made at low cost
- Improve the aesthetics of the product
- Not have any sharp edges

A few options were explored, looking at both low and high cost initial investment alternatives.

Idea 1 bucket

This idea makes use of a bucket to support the entire gasifier. The idea is that the stove can be sold separately from the electrical components. This would allow the gasifier to function with natural draft only. Of course it will not have the high efficiency that a stove with a fan supports. However, it will provide a cleaner combustion then traditional open fires. The fan and electronics can be incorporated into the bucket to store them safely from dust and moisture. As in Rob his gasifier design the choice could be made to make the bucket from concrete using a mold. This would provide good stability due to the weight. Other materials could be plastic using injection molding or sheet metal.

Image 6.6.1: Sketch of idea 1 bucket stove support

Image 6.6.2: Idea 1 bucket bottom view

Idea 2 sheet metal

As a low cost option two plates of cut and bended sheet metal can be used to make three support legs. Image 6.6.3 shows how the two plates are locked into each other. Once the two plates are slid into position the feet can be mounted to the main body using screws. A big advantage is that the plates can be stacked to a small volume so they can fit into the reactor during transportation from the manufacturer to consumer.

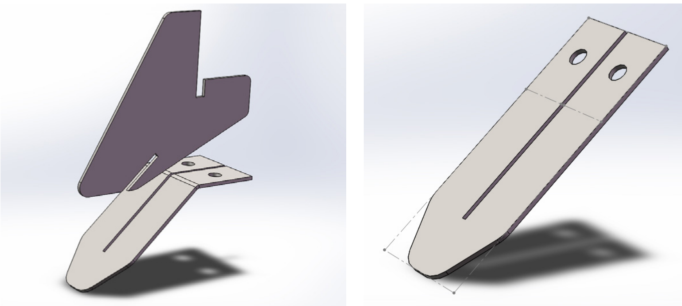


Image 6.6.3: Sheet metal feet

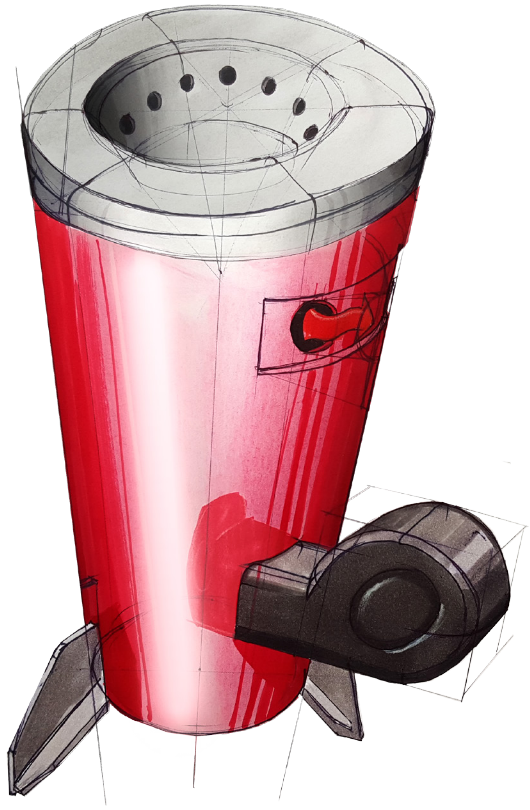


Image 6.6.4: Sketch of idea 2 sheet metal feet

Idea 3 Injection molding

When larger production volumes are obtained it can be chosen to produce certain parts using higher cost investment techniques. Through injection molding these pieces can rapidly be produced and fastening features such as a snap connection can be used (the Mimimoto stove for example). Image 6.6.5 and 6.6.6 show how this part snaps into the outer body.

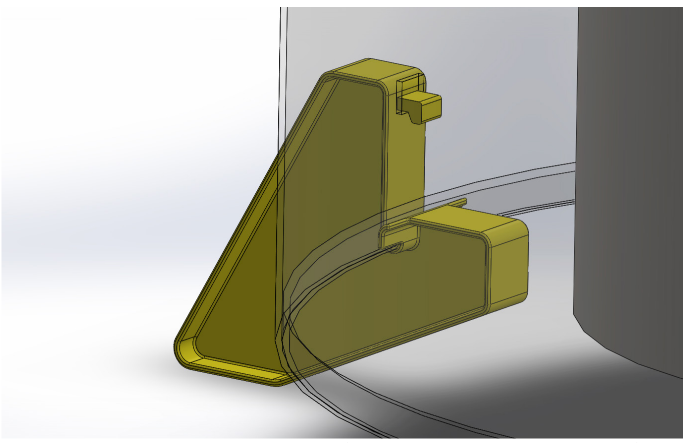


Image 6.6.5: Detail view of the injection molded feet

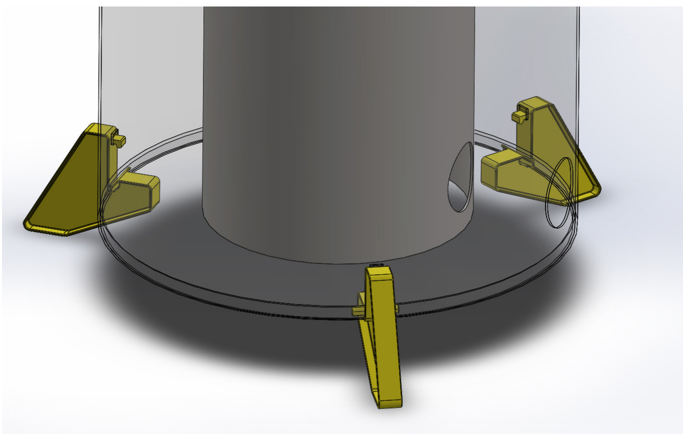


Image 6.6.6: Three feet assembled in the body

6.7 INSULATION

Insulation provides safety for the user and improves the gasification process. Several ideas were developed in order to improve the insulation and decrease the cost.

Glass wool

Most of the previous prototypes relied on fiberglass for thermal insulation. It is a cheap and commonly used material that is durable and can withstand high temperatures. Although this provides reliable results, there are some negative aspects regarding this form of insulation. The main problem is that after a batch operation of around 45 minutes it maintains the heat for almost 30 minutes.

Image 6.7.1: Filling the outer body of the prototype with glass fiberglass insulation

Air chambers

Air can function as an excellent insulator and is commonly used in products such as thermo flasks and windows. In order to use air as an insulator there are two important factors; distance between the layers and insulation of the air. Looking at dual-pane windows the distance between the two layers are relatively small (around 1 cm). Any smaller will cause the heat to diffuse across the air gap to the other layer. However, if you would increase the layer too much it would not be effective either. The reason for this, is that with a larger distance the heat by bulk motions in the air gets more efficient. This would even happen if the air is completely insulated and cannot move anywhere outside. Therefore, it can be stated that the gap between the insulation layers should be small enough to suppress convection and large enough to stop conduction.

For the production very thin metal sheets can be used, such as aluminum, which is light weight and commonly available. The images below show how four air chambers can be created within the gasifier.

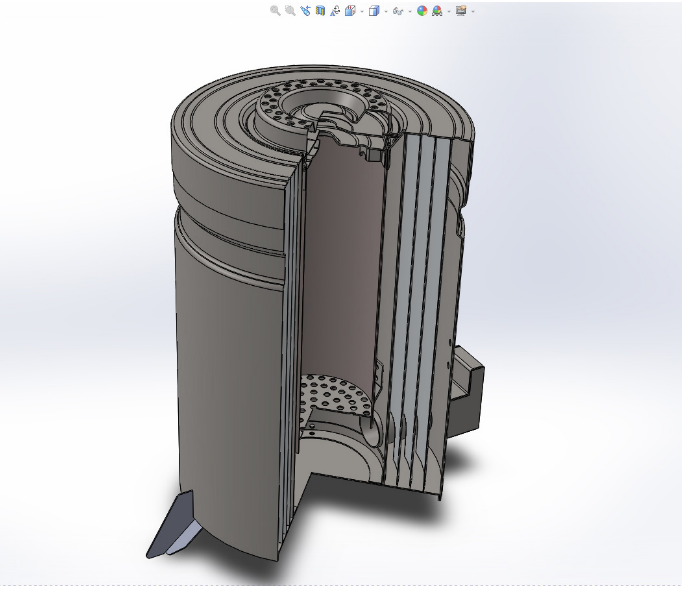


Image 6.7.2: Gasifier with air chambers

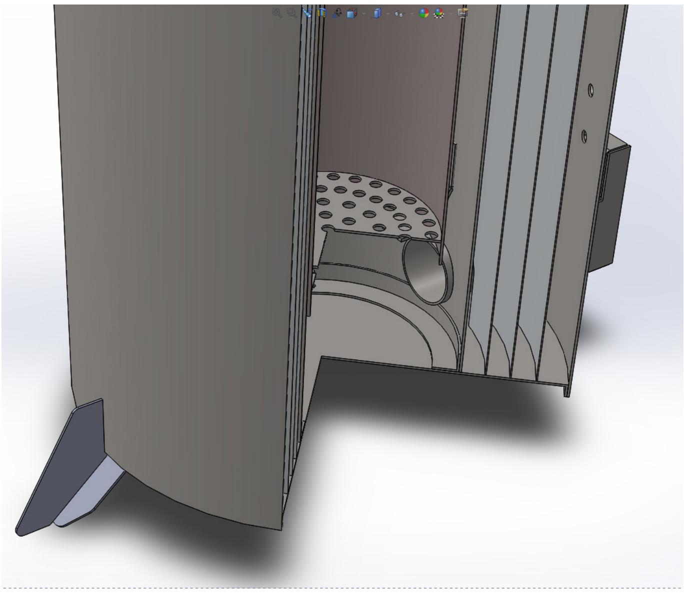


Image 6.7.3: Close-up of the air chambers

Air flow insulation and cooling

Another option is to use the flow of the secondary air to cool the outer surface. A positive aspect of this approach is that the secondary air has more time to absorb the heat before it is mixed with the produce gas. This means that the produce gas is not cooled before the combustion and higher flame temperatures can be reached. A schematic of the airflow is presented in image 6.7.4 below. Although this method might benefit the efficiency it can also add to the cost as it adds to the complexity and more parts are needed.

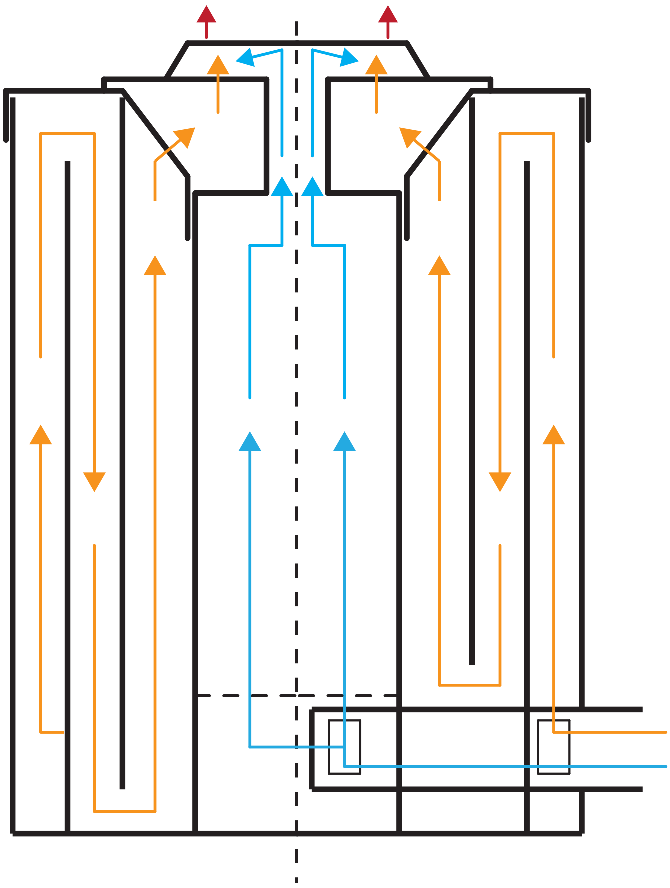


Image 6.7.4: Schematic of the airflow insulation and cooling principle

Water insulation layer

Using the waste heat from the insulation a water storage layer can be introduced. While cooking, the heat that comes from the reactor will then heat the water that is filled in the outer layer. After the cooking task the water can be used for cleaning the dishes, washing or tea. A schematic overview of this principle is given in the image 6.7.5.

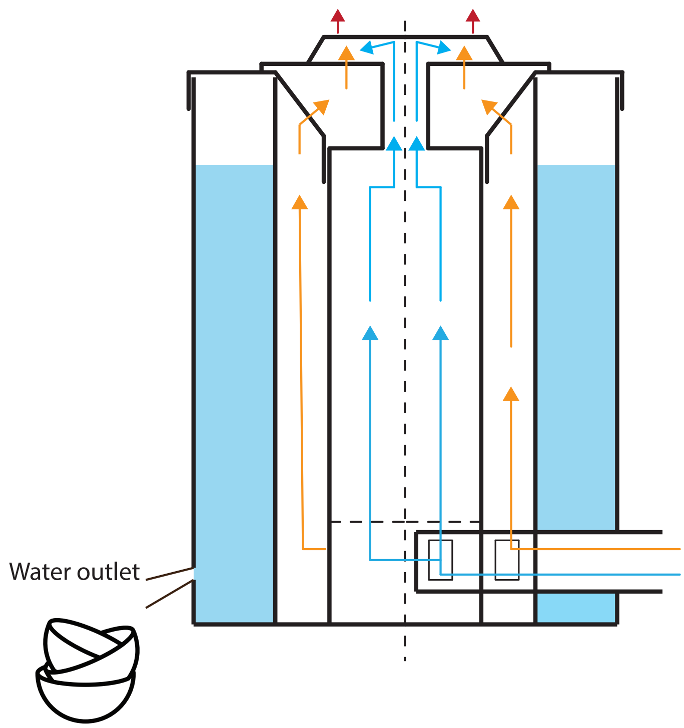


Image 6.7.5: Water insulation layer

6.8 HANDLES

The handles will allow the user to move the stove during or after using it. The main criteria is that it maintains cool enough for users to grab it safely. The handles can contribute to the aesthetics as it can become an appealing detail of the product. Keeping the handles cool can be done by decreasing the contact area of the stove with the body or by using a material with insulating properties such as wood. Several low cost options have been explored and are presented below:

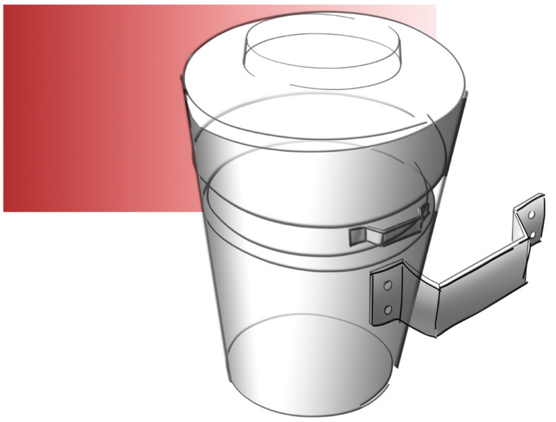


Image 6.8.1: Handles idea 1

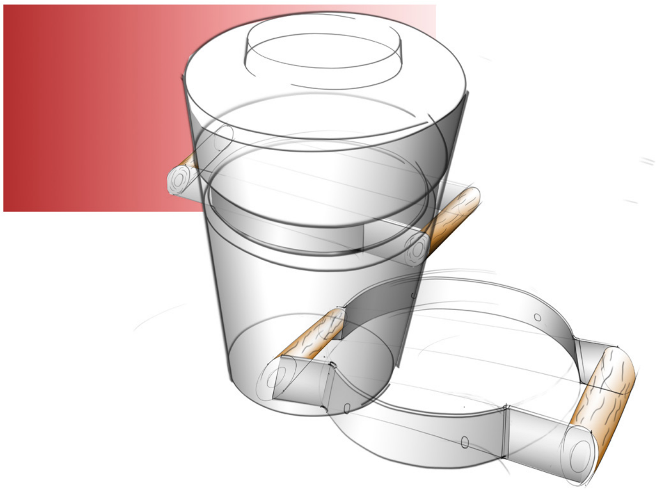


Image 6.8.2: Handles idea 2

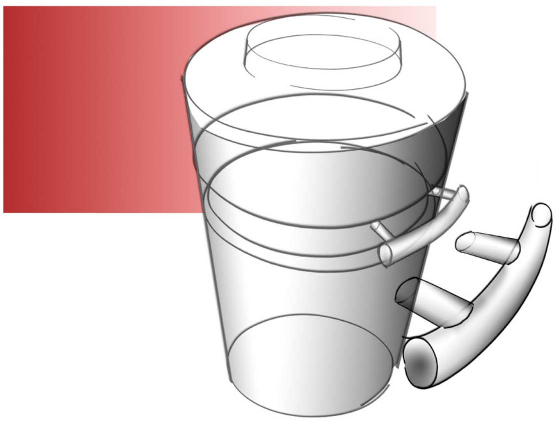


Image 6.8.3: Handles idea 3

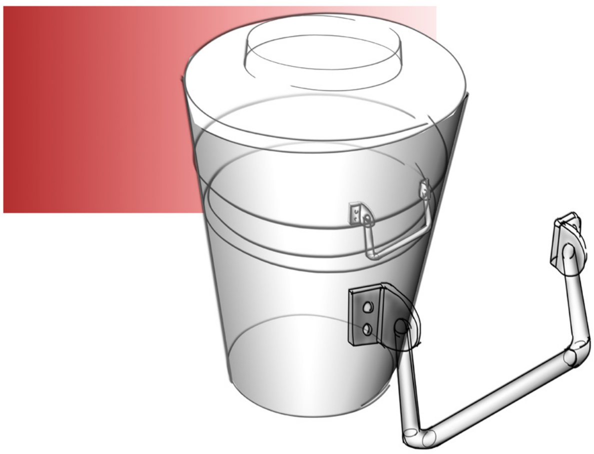


Image 6.8.4: Handles idea 4

6.9 ELECTRONICS

In order for the user to adjust the intensity of the flame (for different turn-down ratios) a rotary control switch can be used. This can be performed by using basic electronics, it can therefore be chosen to produce this part ourselves. Another possibility is to buy a completely assembled unit from stock (image 6.9.1 on the right). The electronics consist of a microchip that converts the position of the potentiometer to an output voltage for the fan. A LM317/350 voltage regulator is commonly used for this application and is low cost.

Image 6.9.1: Stock electric unit

Image 6.9.2 on the right can be used for indicating the position of the rotary control switch relative to the intensity of the flame.

Electronics that are required consist of:

- A 12V DC adapter minimal 500 mA.
- A LM317 voltage regulator
- A 10 KΩ potentiometer
- An LED for indicating that the fan is powered on
- A centrifugal fan
- A 0.1 uF capacitor
- A 1 uF capacitor
- A 1 KΩ resistor
- A 2.2 KΩ resistor

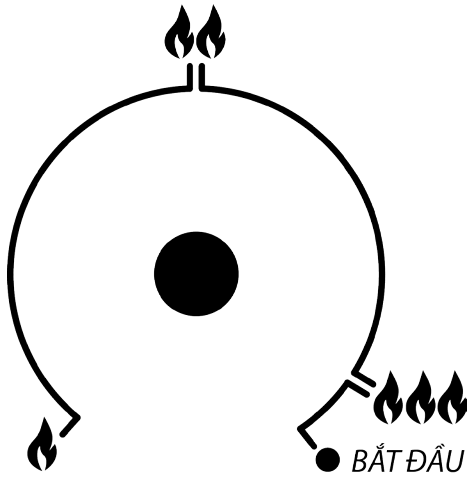


Image 6.9.2: Flame intensity indicator

An overview of the electronic circuit is given in image 6.9.2 below:

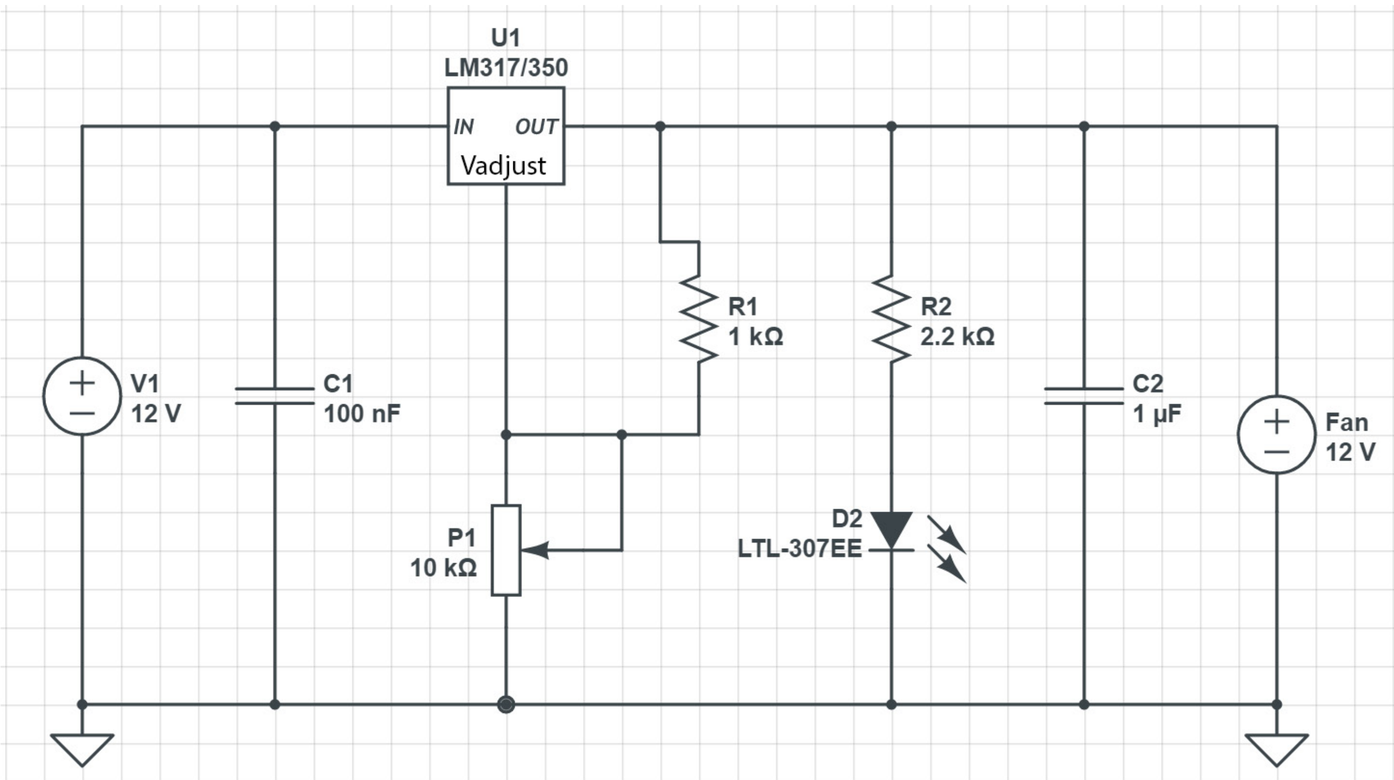


Image 6.9.3: Electronic circuit diagram

6.10 BODY

The body of the gasifier can improve the aesthetics of the stove and provide support/ fastening features for other parts. One of the additional features that should be implemented, is a way to cover the fan and electronics safely. Until this point the fan and control parts have just been sticking out from the side making them vulnerable for external forces. Features the body can/ should support are:

- Be robust to protect the inner components
- Improving the aesthetics of the product
- Easy cleaning of the outer surface
- Low cost
- Store electronics
- Provide easy access to adjust the fan speed
- Provide protection from the wind

First some shapes have been explored on which ideas were built. Until now the gasifier has had a cylindrical shape, reason for this is that it can be made at a low cost with basic machinery. Adding beads can enhance the looks and stiffness of any metal and are therefore added to shape 2 and 3. This is commonly used in oil barrels or cylindrical polymer packaging. Some presentation sketches haven been documented in appendix G.5 to explore several other ideas about shapes and color that could be used.

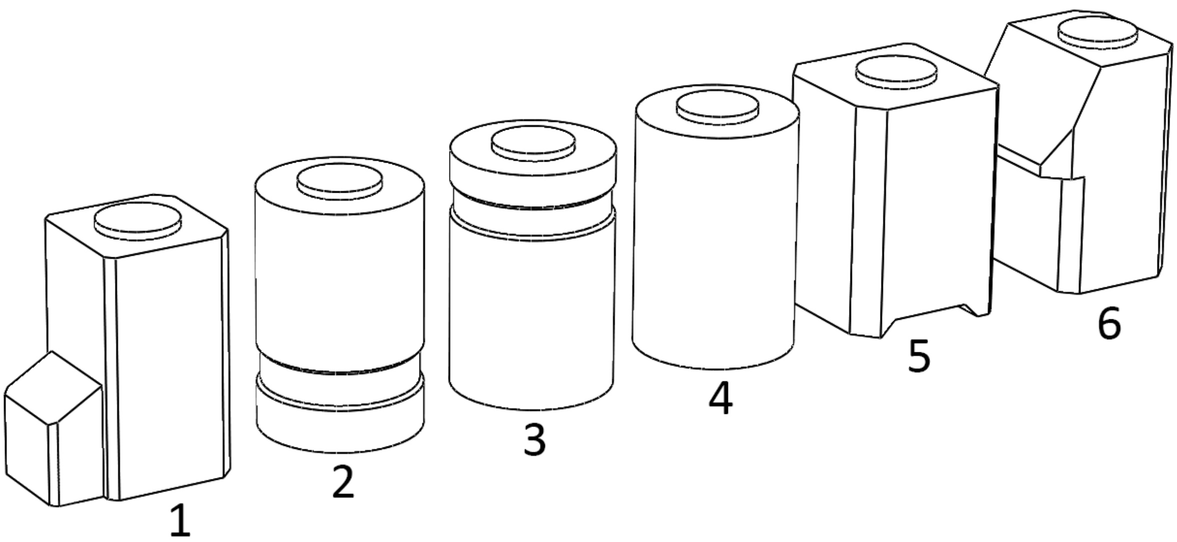


Image 6.10.1: Different shapes for the gasifier body perspective view

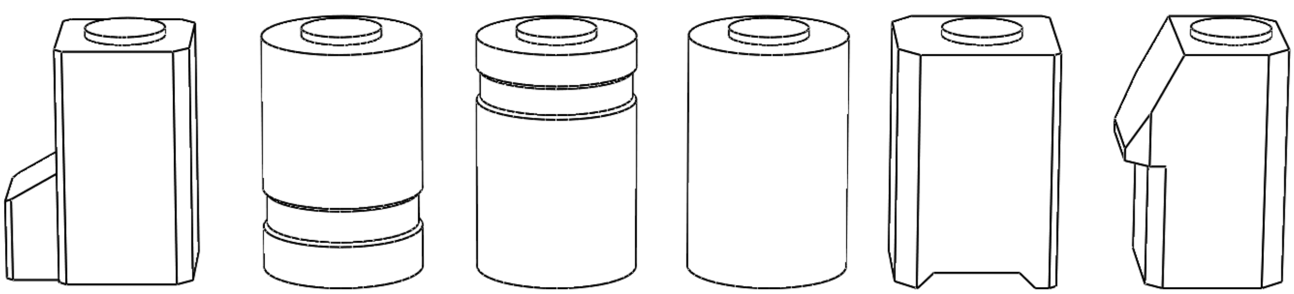


Image 6.10.2: Different shapes for the gasifier body front view

6.10.1 Electronic storage box

Besides the body, the electronic storage box is one of the components which can easily be changed when improving the aesthetics. Keeping in mind that this component should provide be low cost several options have been explored which can entirely be produced from sheet metal components. More images of different ideas are documented within appendix G.3.

Idea 1 Curved box

The first idea presented in image 6.10.3, is inspired by the shape of the fan. As the fan is placed in a flat potion the curvature of the box flows around it. The curved top surface should prevent liquid spillage from cooking to accumulate on top and flow of easily. In the top, there is enough space to place the electronics.

Image 6.10.3: Gasifier with curved storage box

Idea 2 Simplified box

Compared to the first idea this box presents a more basic shape The straight angles in the sheet metal make it a lot easier to produce this part. Instead of a perforated lid, lances are made for the air to enter. This prevents any fluid that is spilled to enter the box. The edge at the side is slightly overlapping the edge for the same reason.

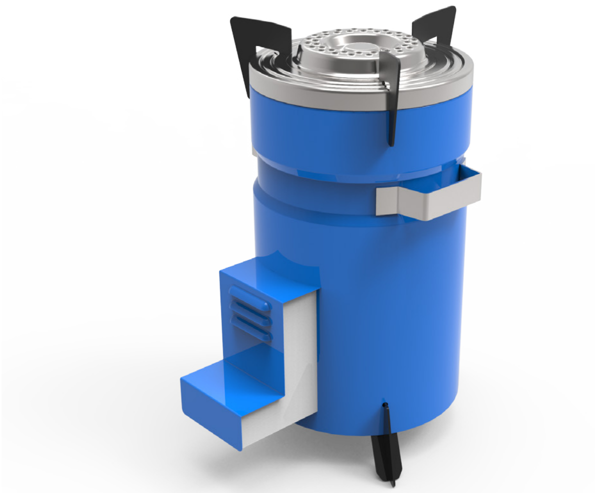


Image 6.10.4: Gasifier with simplified shape storage box

Idea 3 angled box

In this idea the orientation of the fan is changed to a vertical position. The reason behind this was to decrease the volume of the box which would make it appear smaller. Though this might be true for the front view, when looked from at the side it sticks out. The box provides easy assembling with sheet metal fastening. All the electronics are mounted to the lid and fastened by folding the four flanges around it.

Image 6.10.5: Gasifier with angled box and sheet metal fastening

Conclusion

During a discussion about these presented ideas, it was concluded that the optimal shape was not yet obtained. Additional efforts have been made to improve this part and is presented in the final concept in chapter 6.12.

6.11 ADD-ONS

Stand alone solution

For some market segments it is necessary for the product to work completely autonomous. This means that besides the stove the only thing needed to operate it should be the fuel, starter material, the cooking pots and food. There are several solutions to solve this problem.

- Rechargeable battery with which the stove can operate for several hour
- Rechargeable battery + Power generation from waste heat with the use of a peltier element
- Rechargeable battery + Power generation from other energy sources such as battery packs or solar panels

The main consideration of implementing one of these solutions are the additional cost. One of the possibilities is to provide a solution that is modular so it can be sold as an add-on to the current design. A idea has been developed to use the heat from the gasifier as an energy source to charge a battery and power the fan. Looking at the sketch below, one side a peltier element is cooled by the air passing the heat sink. The other side could be connected with copper to the reactor to transfer the heat.

Another possibility is to use some of the secondary airflow to heat the side of the side. This documented in appendix G.4.

Instead of a separate housing this unit could also be implemented in one of the electronic boxes presented in paragraph 6.10.

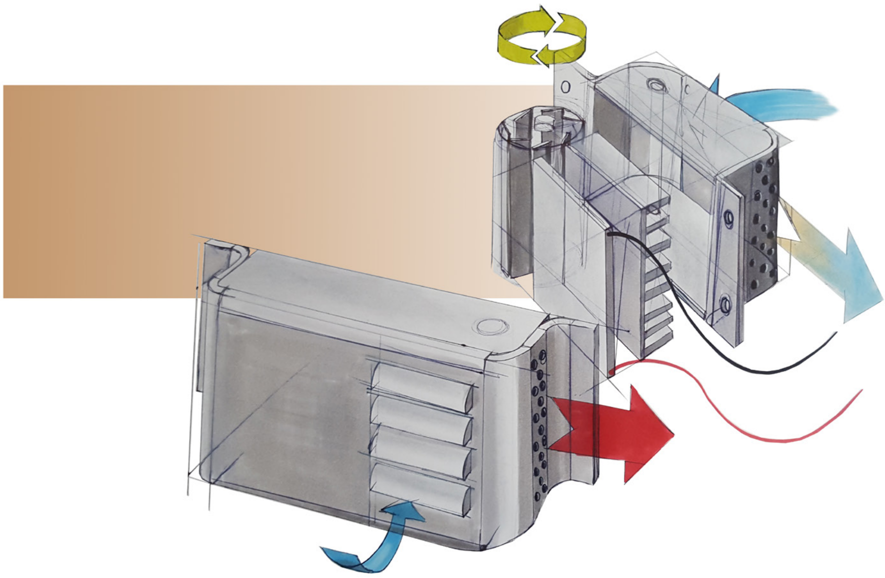


Image 6.11.1: Heating and cooling of the peltier element for electricity generation

Plier

For placing the burner and maintain the fire in the stove a plier has to be developed. Four identical clips have been placed on the different burner parts and inside the reactor so they can be taken of the gasifier during or after the cooking operations.

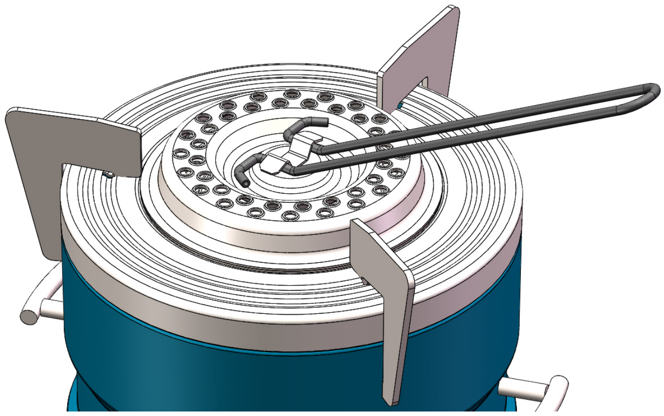


Image 6.11.2: Plier grabbing the burner top

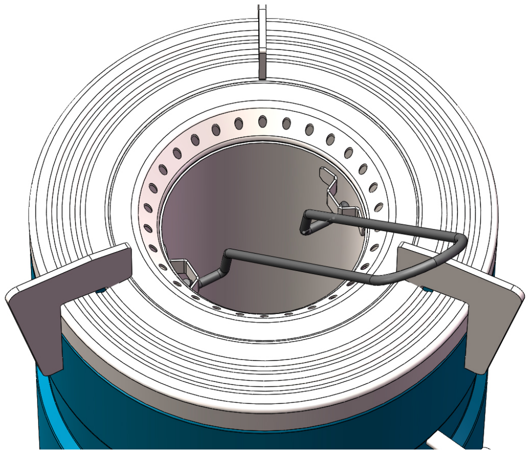


Image 6.11.3: Plier grabbing the reactor

Wind shield

A wind shield would be good for consumers that cook outside. This will primarily be good for street food vendors as most other people in different segments cook inside. It was also observed within the streets of Hanoi a lot of people used self-fabricated windshield from scrap metal.

Image 6.11.4: Idea of a wind shield add-on

Provide heat and light

From the secondary user needs it is determined that some of the people within the lowest income segments, use their traditional fire to also provide light and heat, besides cooking applications. Though most people in Vietnam are well connected this might be a feature that has to be developed when targeting this market.

6.12 FINAL DESIGN

In previous chapters have analyzed each component individually. The goal was to develop a user friendly, safe and efficient biomass gasifier stove for Vietnamese households which can be sold at an affordable price. This paragraph will briefly describe the concept and the design considerations that have been made.

Cost

As mentioned before, the cost is one of the most important factors to consider. Looking at the financial recourses of the company, it is chosen to allow this concept to be made using low investment manufacturing techniques. Transportation can increase the cost. Therefore, detachable pot support structures and feet have been made that can easily be installed by the user to decrease the packing size.

Handles

The handles have been made low cost from three pieces of stainless steel tube (Ø 8mm) that are welded together. The shape of the handles follows the shape of the curvature of the body.

Efficiency

The way the efficiency is optimized, is by increasing the speed of the produce gas, decreasing the turbulent flow of the gas inside and optimizing the mixing of the secondary air. This makes the flame burn on top of the burner ports releasing the energy from the combustion reaction close to the pot.

The burner consists of two sheet metal components that can be made with one or more stamps of a mold and a reactor cap that is made by spinning. The burner is optimized to increase the efficiency and allow the stove to be operated with different turn-down ratios.

Usability

Compared to the prototype of CCS, with which this project started, the usability is also improved. The funnel that is integrated in the top plate allows for both easy filling of the fuel and makes the gasifier more suitable for other types of non-processed biomass fuels.

Image 6.12.1: Final design

Image 6.12.2: Close-up of the burner with pot support

Electronic storage

In order to safely store the electrics, a box is added to the side. This box can be made completely from sheet metal operations (bending, cutting and punching). A potentiometer can adjust the fan speed and a LED at the top indicates if the device is powered on.

The fan is placed horizontally and is connected with the air-tube through a connection piece which is also made from sheet metal. In total there are just five sheet metal pieces to form this box.

Image 6.12.3: Assembled view of the electronic storage compartment

Image 6.12.4: Exploded view of the electric storage compartment

Image *6.12.5*: Exploded view of the electronic storage box

Component overview

An overview of the different components within the gasifier is given in the image below.

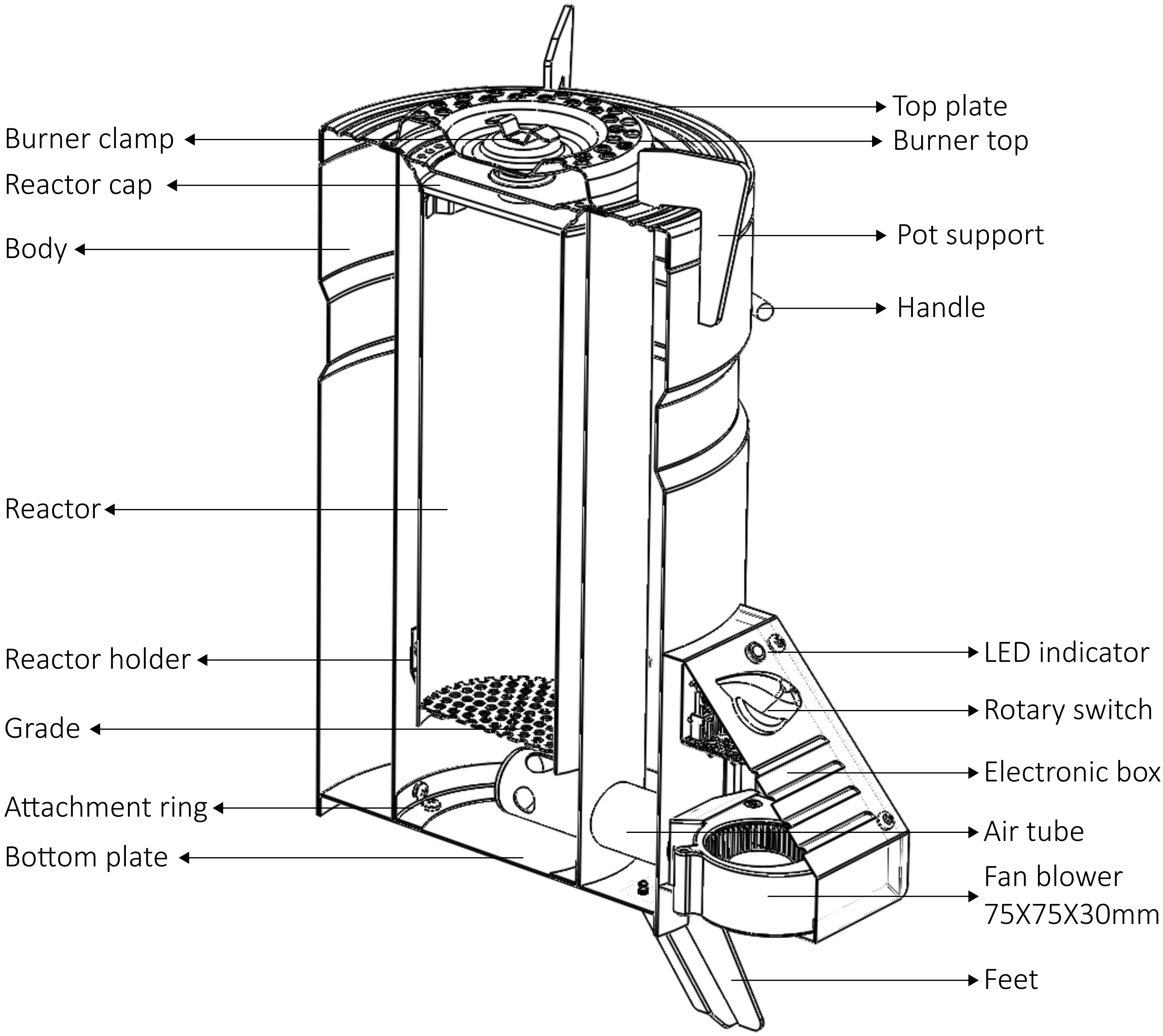


Image 6.12.6: Cross section of the gasifier concept

7 DETAILING

7.1 INTRODUCTION

In this chapter the embodiment of the final concept is presented. First the material selection is specified for all the components (7.2). Following the different production methods are explored to make an educated decision on what can be used (7.3). This will be dependent on criteria such as investment costs for tooling and form freedom of the production technique.

The fourth paragraph (7.4) will show the assembly steps of the product and how the product is optimized for better manufacturing and assembly.

The fifth paragraph (7.5) will give an overview of the buy in components. These are parts which are not produced by the company but can be bought in bulk from suppliers.

The sixth paragraph (7.6) will give a cost estimation of the different parts individually and a total cost estimation of the final design. The assessment of the cost for each part is based on an interview with a production expert in Vietnam. Also a cost estimation by a large scale production company in Vietnam is presented. This cost estimation is of a design previous to the final design, but can be used as reference material.

7.2 MATERIAL SELECTION

7.2.1 Introduction

This paragraph describes the materials that can be chosen for the production of the parts of the final design. Factors to be considered that are specific for each material includes:

- Mechanical properties (strength, flexibility, fatigue life)
- Physical properties (expansion and contraction)
- Thermal properties
- Availability and price

Ideally, the material choice would be based on known data, obtained from practical experience. Looking at the design, there are parts that have to withstand high temperatures. Based on stoves in the market it appears that cast iron products last longer than sheet metal components. Not much is known about the actual life span of these parts when they are used for significant longer periods of time.

Material used in prototype

The steel type that has been used during prototyping and for the older gasifiers of CCS is a stainless steel 304 (UNS S30400, iron, 19% Cr, 9% Ni, 0.08% C). This type of stainless steel is suitable for clean oxidizing conditions to about 900°C in continuous service, or 845°C in intermittent temperature cycles.

As was detected during tests, overheating is the most common cause of high-temperature corrosion failure. Through testing it is found that the surface temperature of the old burner can reach temperatures between 800°C - 1000°C. This is mainly caused when the flame is burning inside instead of on top of the burner ports. This poses a significant problem towards the life cycle of the burner. In the images on the right, looking at the old prototype of CCS, it became visible that after just a few tests, the thickness of the stainless steel parts decreased and corrosion was formed on the surface.

Image 7.2.1: Picture of the burner prototype before usage

Image 7.2.2: Picture of the burner prototype after several times of usage

7.2.2 Applied materials

Several options have to be explored in order to provide the best solution for the product. As discussed, some parts of the stove have to operate in high temperatures. Therefore, maximum service temperature is one of the criteria that is important for selecting the right material.

A flow chart has been made in order to select the right material for each part. A distinction has to be made between components that have to operate in high or low temperatures. This would include parts such as the burner, the reactor and the reactor cap. Then there is a difference if the parts have high forces acting upon them (structural) or almost no external forces (functional). For example, the pot support which has to withstand the weight of a big pot, might get very hot which weakens the material. It should therefore have an increased thickness or be made of a stronger material. Lastly a distinction is made between parts which are visible or invisible for the user. This is a price consideration, as stainless steel is generally more expensive, only the parts that are visible could be made of this type of steel or be coated.

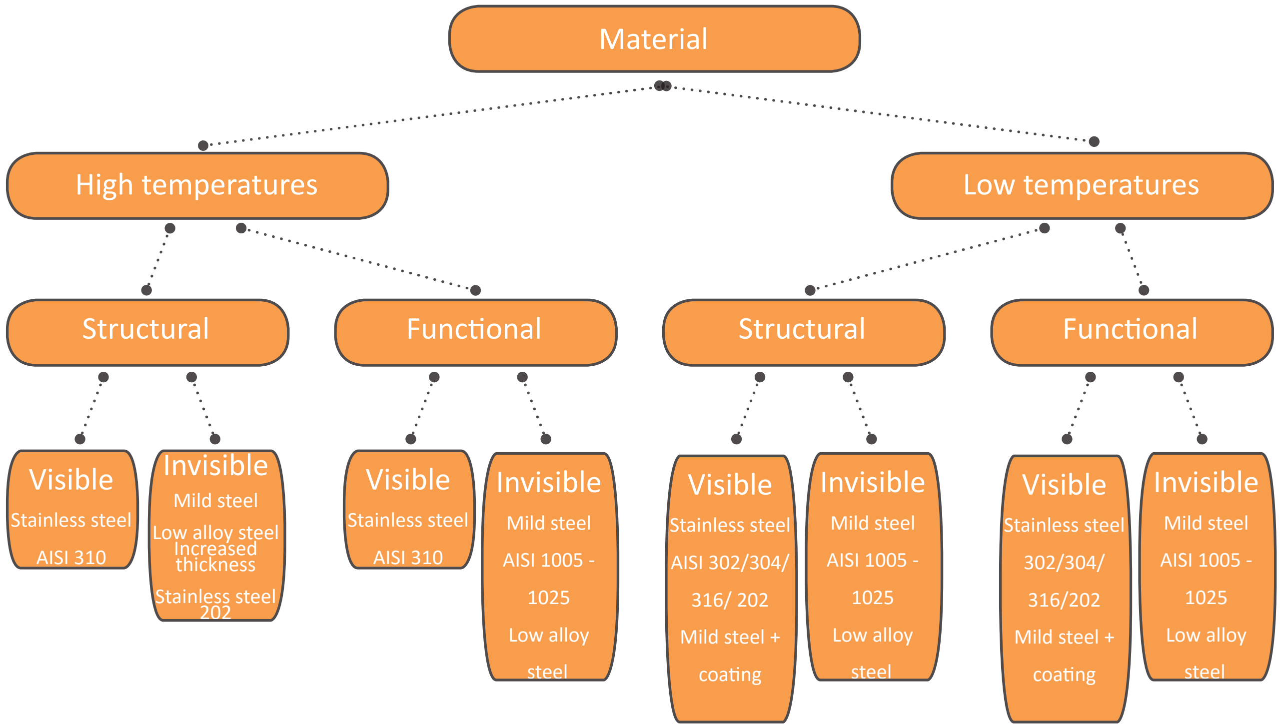
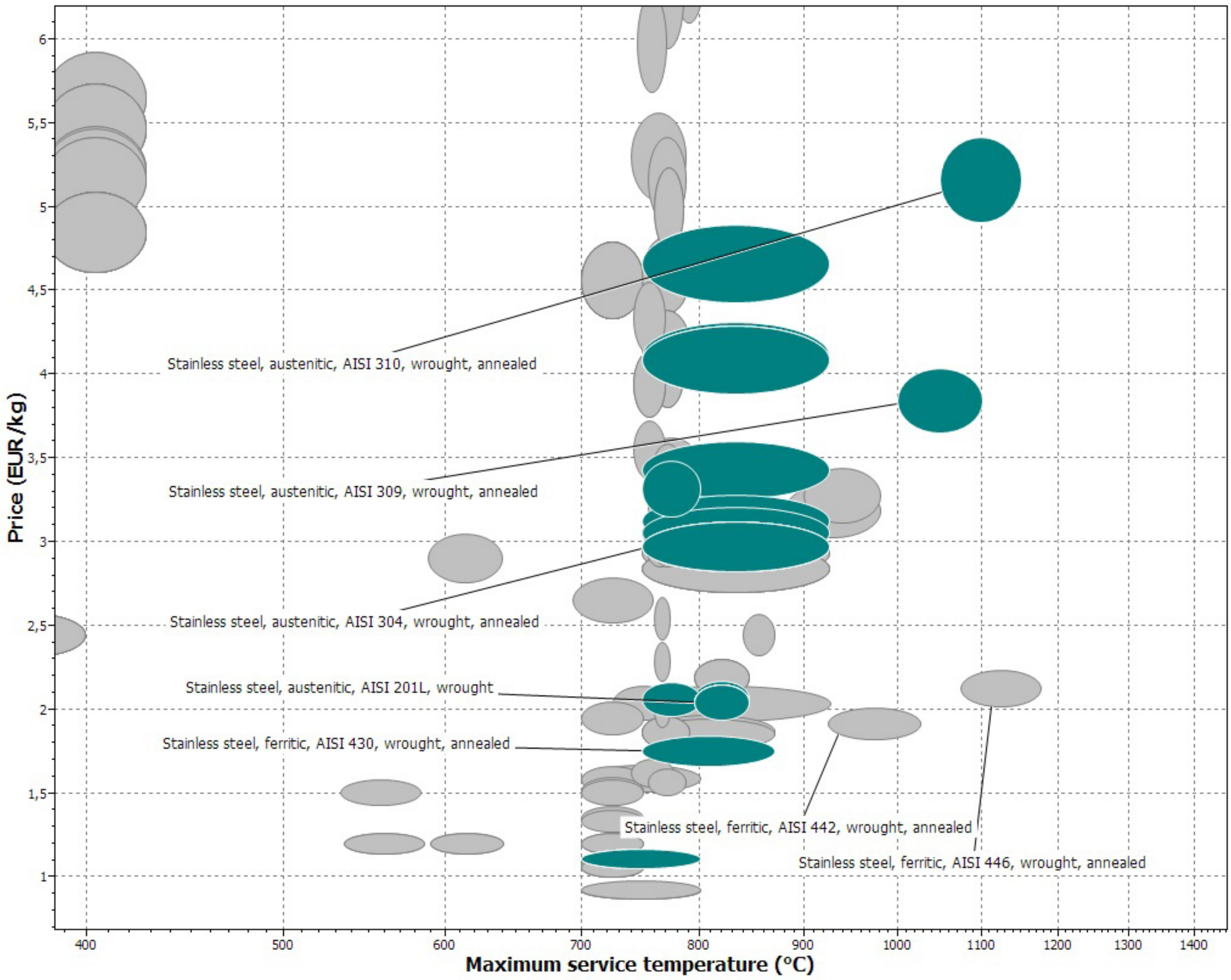


Image 7.2.3: Flow chart for material selection of different components

The materials presented in the graph below are selected using the Cambridge Engineering Selector (CES, 2015). By filling out criteria such about processability (such as sheet metal forming operations), thermal properties and price several material options can be plotted into a graph. It has to be noted that the price/ kg can alter among different suppliers. Looking at the graph it can be observed that stainless steel AISI 310 has the best thermal properties and can be used in intermittent service in air temperatures up to 1040°C and 1150°C in continuous service. Cheaper options, as well as more common stainless steel grades are AISI 304 and AISI 309. Only the blue colored materials in the graph are suitable for metal forming operations such as deep drawing and press forming. Mild steel grades AISI 1005 - 1025, are common and very suitable for these operations as well.

The modular design approach allows parts of the gasifier to easily be replaced. This means that mild steel can also be used to replace materials such as ASISI 310 but this will definitely lower the life span. It would decrease the acquisition cost for the user. This is however not recommended as people might lose their trust in the product in the long run.



Graph 7.2.1: obtained from CES

7.3 PRODUCTION

This project is focused on making a product that is suitable for mass production, therefore different options for mass production are explored. Based on the current design (image 7.3.1 below) a few different production techniques can be considered. The following criteria will determine the most suitable choice:

- Investment cost for special tooling should be low
- Maintenance cost for tools
- Quantities ranging from 500 for the first production batch to over 10 000 annually can be produced
- Quality of the produced parts
- Availability of production equipment in Vietnam
- Form freedom permitted by the production process
- Aesthetic results of the fabricated parts
- Suitability for the design
- Production time

These following mass production techniques fit the criteria. For some parts a mix of production techniques have to be used. Information was gathered from custompartnet.com ("Sheet Metal Forming", 2016)

- Deep drawing
- Spin forming
- Investment casting
- Sand metal casting
- Punching
- Blanking
- Fine blanking
- Rolling
- Bending
- Turning

Image 7.3.1: Exploded view of the final design

7.3.1 Deep drawing

Deep drawing is a metal forming process in which sheet metal is stretched into the desired shape of a specific part. A tool pushes downward on the sheet metal, forcing it into the cavity of a die, in the desired shape of the part.

For the deep drawing process four parts are needed, a blank, a blank holder, a punch, and a die. (Image 7.3.2 on the right). The blank is a piece of sheet metal, typically a disc or rectangle, which is pre-cut from stock material and will be formed into the part. The blank is clamped down by the blank holder over the die. The die has a cavity which forms the external shape of the part.

A punch moves downward into the blank and draws, or stretches, the material into the die cavity. This process is illustrated in image 7.3.3 on the right. The movement of the punch is hydraulically powered to apply enough force to the blank.

For some parts of the gasifier it might be necessary to perform the drawing process in a series of operations, called draw reductions. In each step, a punch forces the part into a different die, stretching the part to a greater depth each time. After a part is completely drawn, the punch and blank holder can be raised and the part removed from the die. The portion of the sheet metal that was clamped under the blank holder may form a flange around the part that can be trimmed off.

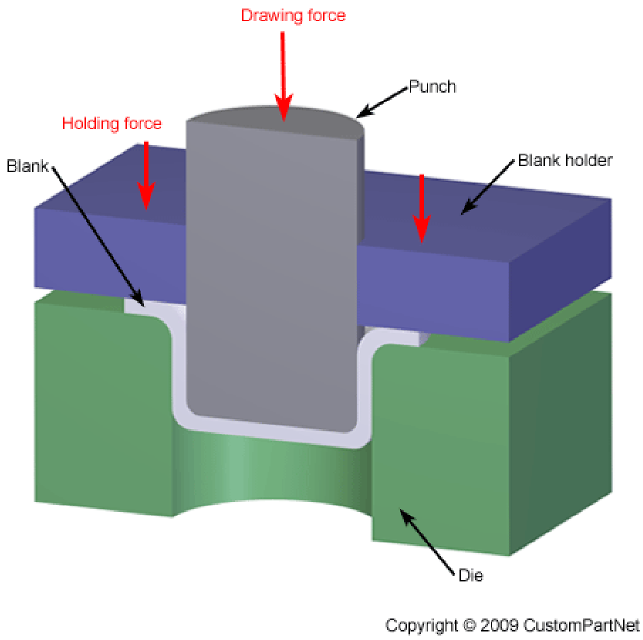


Image 7.3.2: Deep drawing process

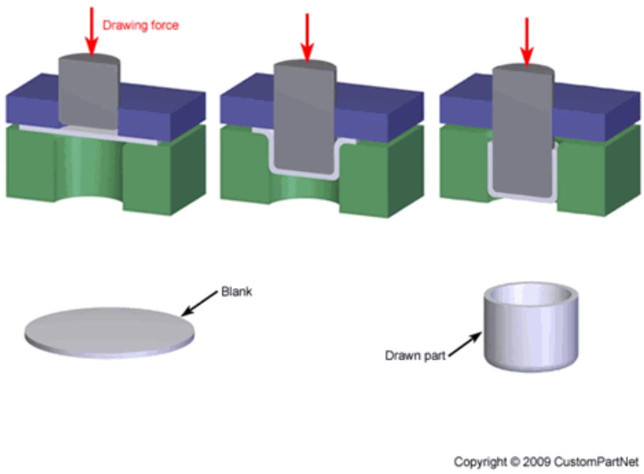


Image 7.3.3: Deep drawing sequence

7.3.2 Spin forming

Specially for cylindrical shaped parts, spinning can be used as a metal forming process. This technique has already been used for making the different prototypes. The parts are formed by rotating a piece of sheet metal with a high speed while a force is applied to one side of the plate. The roller presses the plate against the mold (which is called a mandrel), to form the shape of the part.

There are two different methods for spin forming, one is conventional spinning and the other one is called shear spinning (illustrated in image 7.3.5). With conventional spinning, the roller pushes against the blank to shape it against the mandrel and maintains a constant thickness. With shear spinning the roller applies a bigger force while it moves over the blank. This stretches the material over the mandrel which makes the walls of the part thinner.

Comparison

Comparing deep drawing and spin forming the following statements can be made (Kumar, 2013).

- Spinning produces more accurate parts
- Spinning produces a better surface finish compared to deep drawing
- For small products to be produced in large quantities spinning is not economical
- For small components to be produced in large quantities deep drawing is generally more economical because of its short cycle time
- Failure of components during the process is higher for deep drawing
- Machinery and tooling set for the spinning process is simple
- Machinery and tooling set for deep drawing process is not simple and is heavy
- Mechanical properties of spinning are better compared to deep drawn products (depending on the depth of the part)

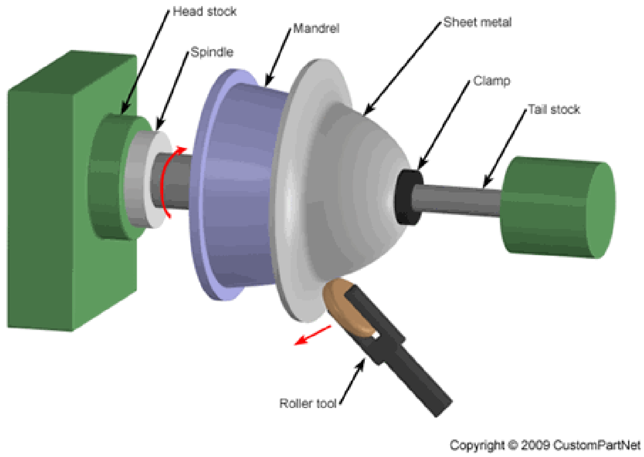


Image 7.3.4: Spin forming process

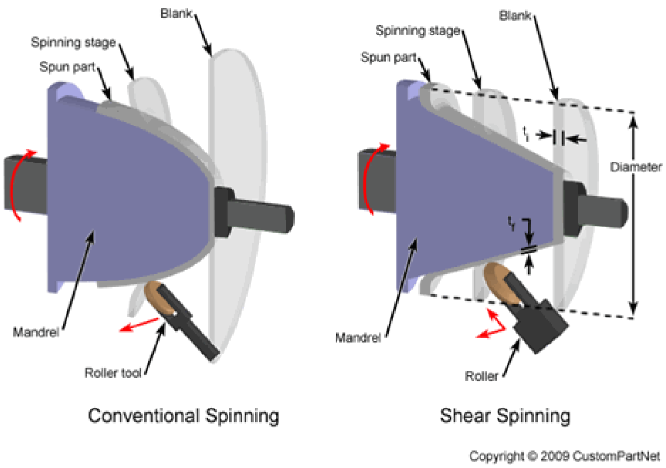


Image 7.3.5: Conventional spinning vs. shear spinning

7.3.3 Applied production method

Depending on the aimed production volumes drawing/ press forming does provide a better solution for higher quantities. The images below show the parts that need to be produced according to this production method.

Part manufacturing

The parts that are showed on this page image 7.3.6 - 7.3.10, are all manufactured from a larger sheet of metal. First the initial shape is pressed. After which several secondary operations have to be performed. For the top plate, the connection ring and the bottom plate, the flange has to be removed. The burner top and burner bottom will use the flanges to weld them to each other. The third step is to punch the holes. This can either be done manually or with the use of another stamp press operation. This would require fabricating an additional mold which could punch the holes in one operation.

For the “top plate” in the funnel (image 7.3.8), the punched holes are perpendicular to the top surface. This makes the holes have a shape of an ellipse. It is recommended for the connection ring and bottom plate to punch/ drill the holes manually for lower production volumes, as this would save initial investment costs of an additional mold. In total, eight molds are needed. Five for the shaping process of the parts and three more for punching the holes in the burner components and the top plate.

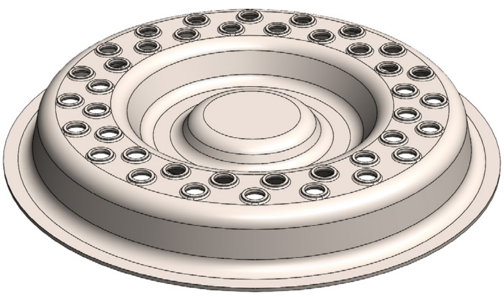


Image 7.3.6: Burner top

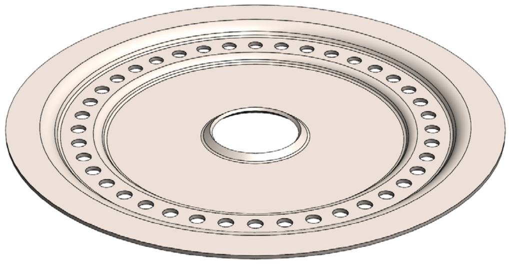


Image 7.3.7: Burner bottom

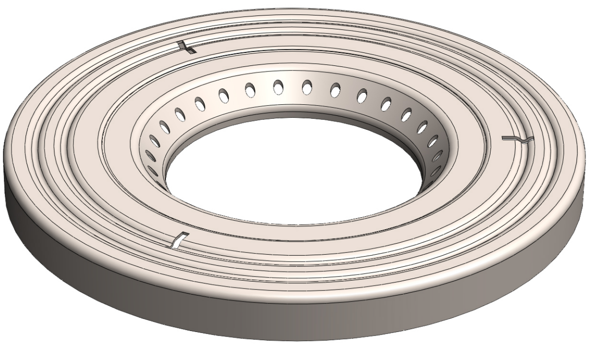


Image 7.3.8: Top plate

Image 7.3.9: Connection ring

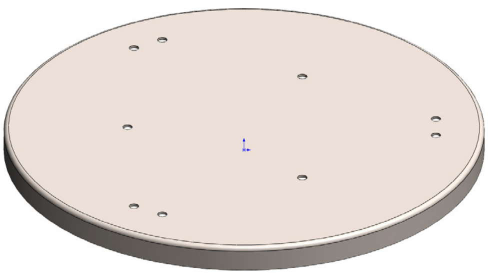


Image 7.3.10: Bottom plate

7.3.4 Metal casting

As an alternative for sheet metal production, metal casting can also be used for the production of certain parts because it has a good resistance to high heat and temperatures changes.

Investment casting

Investment casting process, also referred to as "lost-wax casting", is a process in which parts are formed by pouring molten metal into a mold. The mold is produces by using a wax shape of the desired part. The wax shape is then put into a flask and covered with ceramic slurry to create a shell. The shell is then placed into an oven to melt out the wax leaving a hollow ceramic shell for the molten metal to be poured in.

This process is very suitable for high temperature applications. Typical shapes can be complex thin-walled or solid. The advantage of this method is that there is almost no waste material, and fine detail in the parts can be achieved with high strength. Though more expensive compared to sheet metal forming it might provide a more economical alternative over time, as the durability of the parts is higher.

Production is very labors intensive for investment casting. This makes investment casting only profitable for places where labor cost are low. Typical quantities range from 10 - 1000 unites but higher production volumes can also be achieved.

Sand metal casting

Sand metal casting is a more basic and cheaper method for casting metals. In this process a pattern is made in the shape of the desired part. The pattern can be made with one or multiple parts from wood, plastic or metal.

The pattern is packed into the sand, mixed with a binder, which hardens the sand into a fixed shape. Once the mold is finished the pattern is removed, which leaves a hollow space in the sand of the desired part. The pattern in the sand should be made larger to account for shrinkage during the cooling.

This method can be used for making basic shapes of the part with a lower surface finish. The production rate of this method is about 1 - 20 pieces per hour. Typical quantities range from 1 - 1000 unites. As a design guideline a draft angle between 1 and 5 degrees is advised.

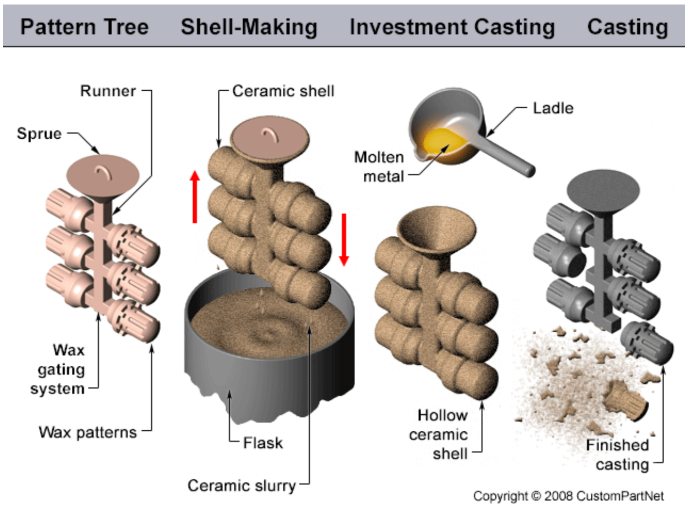


Image 7.3.11: Investment casting process

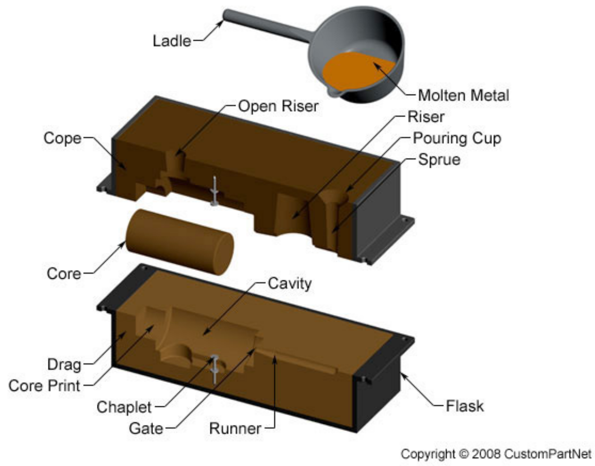


Image 7.3.12: Open mold illustration of sand casting

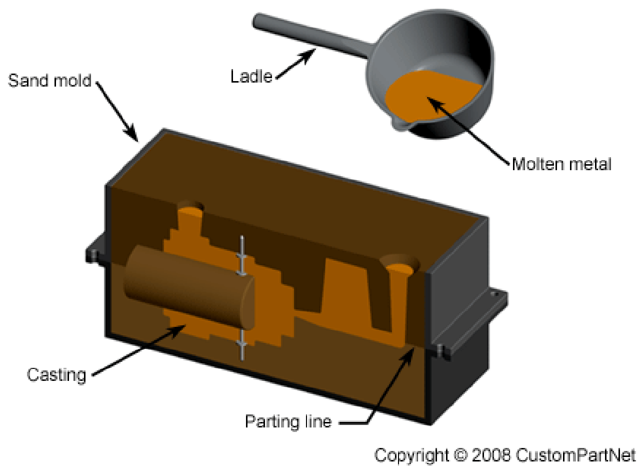


Image 7.3.13: Closed mold illustration of sand casting

7.3.6 Cast iron alternative

When it is chosen to start with a low production volume and see how the market reacts on a gasification cook stove, sand metal casting provides the best alternative.

As an example how this method could be applied to the gasifier design the top plate is modeled as a cast iron component (image 7.3.14 on the right). The pot support can be integrated into the shape which could decrease some of the cost.

The biggest drawback of cast iron is that it can be costly. The process of making a cast iron part is more labor intensive compared to sheet metal. Besides this, in general more iron is used which increases the material costs. Usually these parts can operate between 10 and 20 years without any maintenance.

Comparing sheet metal and cast iron for stove applications the biggest difference in terms of mechanical properties is that cast iron holds the heat much longer (Kalmus, 2011). For a batch operated stove, faster heating and cooling of the material would be more desirable. With cast iron a higher thickness can be obtained which makes the part more durable. Both of these materials can operate safely in temperature between 1080°C - 1180°C for casting (AISI 446) and for sheet metal (AISI 310) between 1050°C - 1150°C.

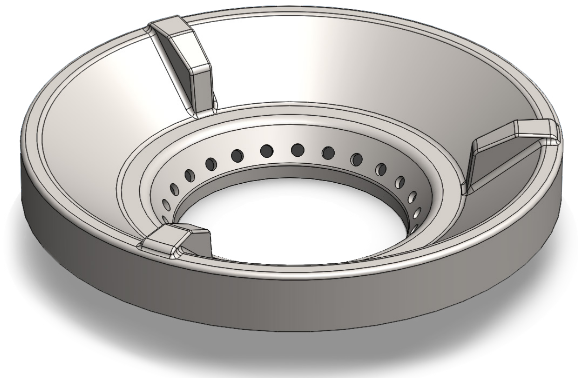


Image 7.3.14 Cast iron top plate

7.3.7 Punching

As mentioned in paragraph 7.3.3, holes need to be punched in the sheet metal for some parts. This sheet metal operation is a cutting process in which material is removed by applying a great enough shearing force. Punches and dies of standard shapes are typically used, but custom tooling can be made for punching complex shapes. Secondary finishing operations can be performed to obtain smoother edges.

Punching procedures are required for the following parts, the same order is used in the table on the right:

- Burner top
- Burner bottom
- Top plate
- Connection ring (piercing or drilling)
- Bottom plate (piercing or drilling)
- Reactor holder
- Body (piercing or drilling)
- Electronic box lid
- Electronic box
- Electronic PCB tray
- Connection rail
- Fan connection
- Universal clamp

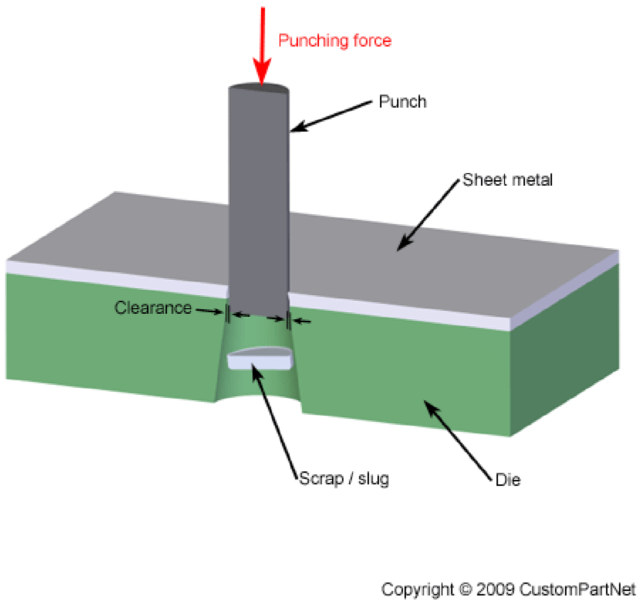


Image 7.3.15: Schematic of the punching process

The table on the right shows the different punching operations that need to be performed for each part.

Special notes

Some parts require special finishes which are noted here:

- The burner ports in the “burner top” need to have a small flange upward. This can be obtained by having a greater clearance in the die.
- Depending on the availability of machinery, the holes in the bottom plate and the connection ring can also be punched instead of drilled. This has a better finishing and is a faster operation. For the bottom plate a special mold can also be built to perforate multiple holes in one go. This is economical for high production volumes.
- The body requires some holes and slots. It can be chosen to punch those in the flat sheet before the cylinder is rolled. This might produce higher tolerances as the position of the holes can be measured on a flat surface rather than a round surface.
- To increase the stiffness of the electronic box some lances have been added. As these are primarily to increase the aesthetics it can be chosen to leave them out in order to decrease production costs.
- The fan connection should be designed in such a way that multiple cut-outs of this parts are nested in the sheet metal plate to decrease the amount of scrap metal.

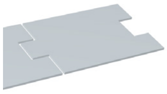
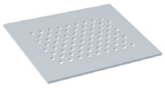
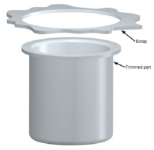
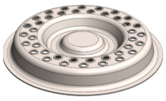
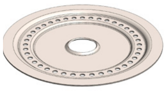
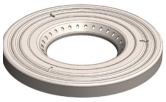
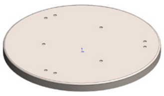
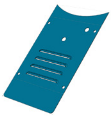
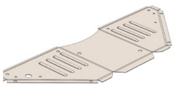
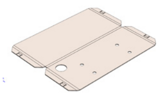
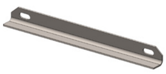
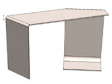
Method							
Part	*Cut-off*	*Lancing*	*Notching*	*Perforating*	*Piercing*	*Slotting*	*Trimming*
				●			
				●			
				●		●	●
					● (Drilling)		●
					● (Drilling)		●
	●				●		
					●	●	
	●	●			●		
	●	●			●		
					●		
			●			●	
	●						
	●						

Table 7.3.1: Punching operations for different parts

7.3.8 Blanking

With blanking, a piece of sheet metal is pressed from a larger piece or plate. In this process the piece removed is called the blank. It is used to cut out parts in almost any 2D shape. The process itself is fast and some automated presses are able to perform over 1000 strokes per minute. Blanked parts typically require secondary finishing to smooth out burrs along the bottom edge. It is also possible to produce parts which require no secondary finishing by using fine blanking.

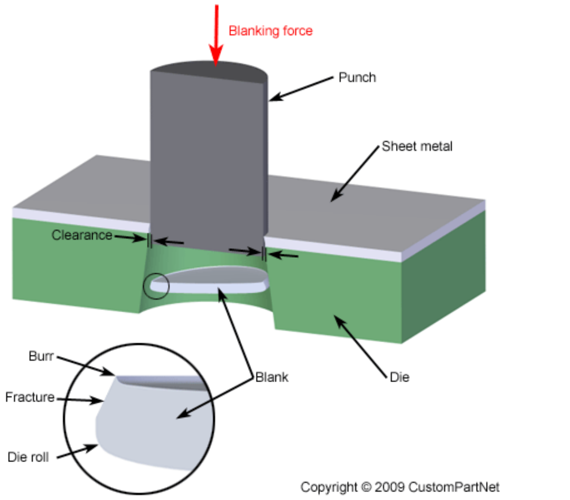


Image 7.3.16: Illustration of the blanking process

Fine blanking

Fine blanking is a method of stamping which produces parts with very tight tolerances and clean smooth edges. Compared to conventional metal stamping it produces a flatter surfaces which results in a completely finished part in a single operation. Tooling costs are higher than traditional metal stamping and requires more maintenance.

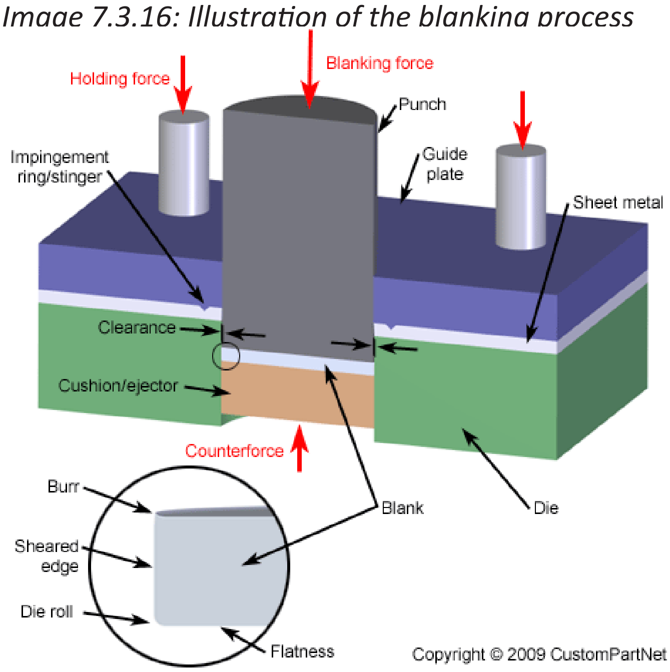


Image 7.3.17: Illustration of the fine blanking process

Part manufacturing

Three parts of the gasifier would benefit from fine blanking. As these are visible components that the user interacts with. Both the pot support clamp and the feet are made of 3 mm stainless steel. To increase the aesthetics a coating can be applied to these parts as well.

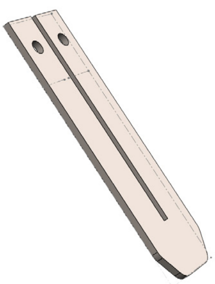


Image 7.3.18: Feet horizontal component

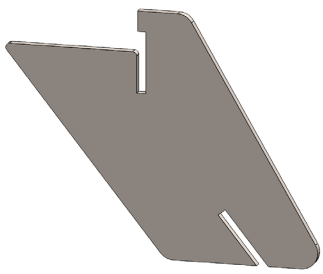


Image 7.3.19: Feet vertical component

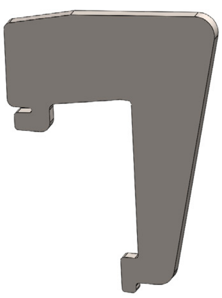


Image 7.3.20: Pot support clamp

7.3.9 Rolling

With rolling, a sheet metal plate is placed between three independent rollers: the middle one (called the pinch roller) applies a pressure which deforms the plate. By making multiple passes between the roller and increasing the pressure with the pinch roller a cylindrical shape can be obtained. To get the right diameter of the cylinder, the sheet metal plate should have the same length as the periphery of the cylinder. This process can be done both manually and automatic.

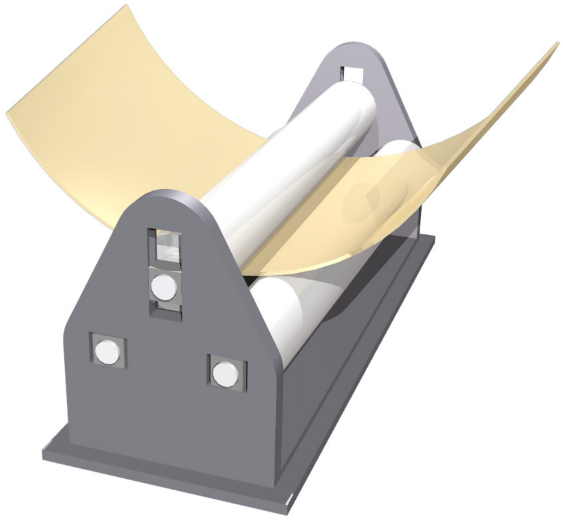


Image 7.3.21: Illustration of rolling process

There are three cylindrical components within the gasifier, which can be produced by rolling of a sheet metal plate, see image *7.3.22* on the right:

- The body
- The inner tube
- The reactor

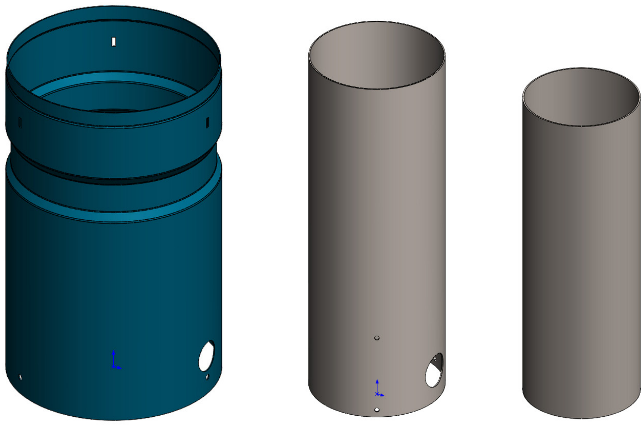


Image7.3.22: Cylindrical parts of the gasifier stove

The inner tube and the reactor can also be produced from standard tubing. This has been done up till now for most of CCS its prototypes. However, to decrease the material costs of these parts they can also be produced from thinner sheet metal plates. Though it will increase the labor cost it might not be an issue when hourly rates are low. Decreasing the thickness does affect the durability, especially for the reactor. It should therefore be tested if this is a feasible option.

Part manufacturing

A common way for joining the edges in sheet metal is by the use of point welding of overlapping seams (image *7.3.23)*. The edges can also be folded making a flat lock seam which requires no welding operation.

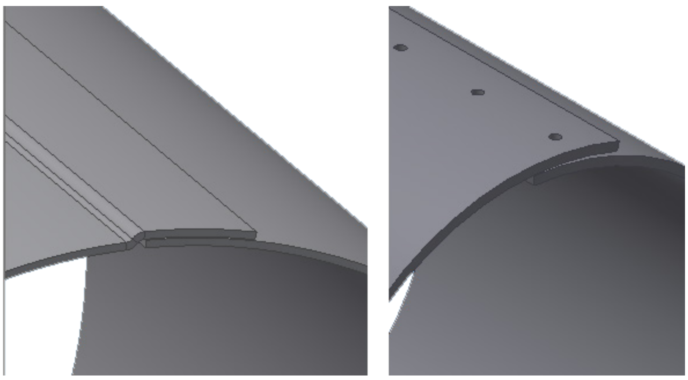


Image 7.3.23: Joining methods for the seams

To increase the stiffness of the body part a bead is placed at the top. This can be produced with simple tools when a suitable “beat roller” is used. Image 7.3.24 shows an example of what this tool looks like. The bead is produced by placing the cylindrical shape in between the two rollers and performing multiple passes between them. With every pass the pressure from the beat roller can be increased.

Image 7.3.24: Bead roller

7.3.10 Bending

Bending is a basic sheet metal operations. It can be performed using simple equipment which can be both automated or manual. V bending is the most common method. The punch pushes the sheet into the "V" shaped groove in the die. If the punch moves all the way to the bottom it is known as "bottoming". If the punch moves down but leaves a cavity underneath it is know as "air bending", with this method a larger radius can be obtained. There are special tools available to make special bends for certain parts. Investing in these tools would make the production go faster compared to manual bending in a basic bend table.

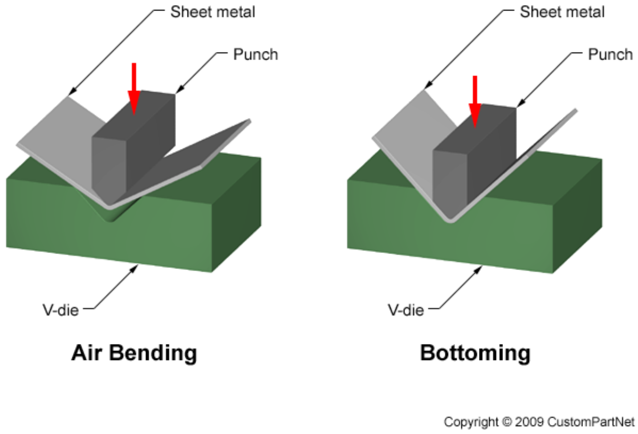


Image 7.3.25: Illustration of V bending process

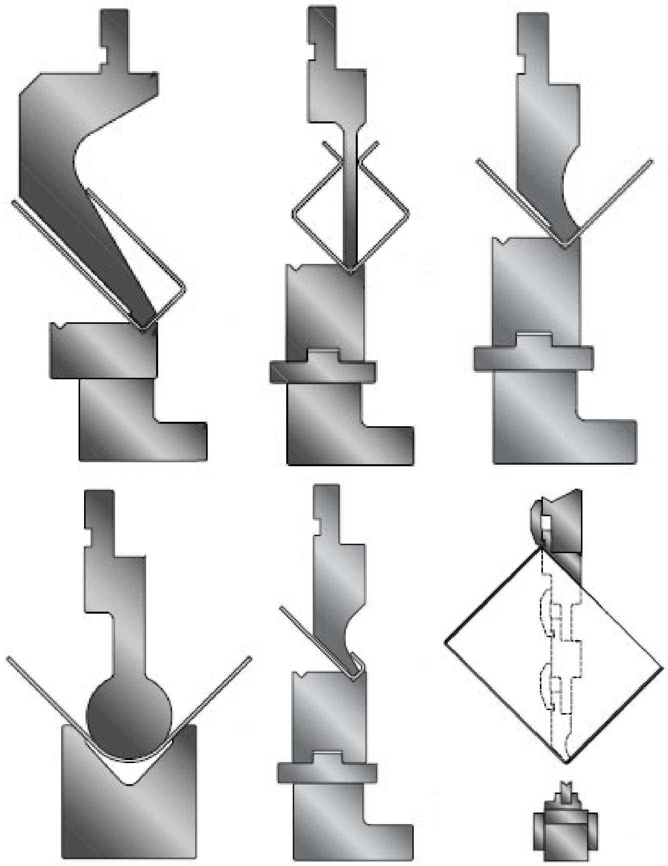


Image 7.3.26: Overview of different bend tools

Design guidelines

The most important guidelines that have been considered in designing the parts are:

- The bend location. There should be enough material present with straight edges for sheets to be secured without slipping. The width of this flange should be equal to at least 4 times the sheet thickness.
- The bend radius should be kept constant for all bends to avoid changing of the tooling.
- The inside bend radius should be at least the sheet thickens.
- Any features, such as holes or slots, located too close to a bend may be distorted. The distance of such features from the bend should be equal to at least 3 times the sheet thickness plus the bending radius.

Part manufacturing

Applying the design theory to the gasifier part, the bending procedures can be described. In total the design requires bending operations for eight components. Within this paragraph only the electronic box and lid have been described in higher detail. The other parts have been documented in appendix H.1.

1. **Electric box**
1. **Electric box lid**
2. Electric PCB tray
3. Feet horizontal part
4. Reactor holder
5. Universal clamp
6. Fan connection
7. Connection rail

Electric box

Image *7.3.27* below shows the folding steps of the electric box. Al bends require a 90° bend with a 1 mm radius. Compared to the final design that was presented in chapter 6.12, the flanges are bended outwards. This should make it easier to bend the large sides upwards, and placement of other parts easier.

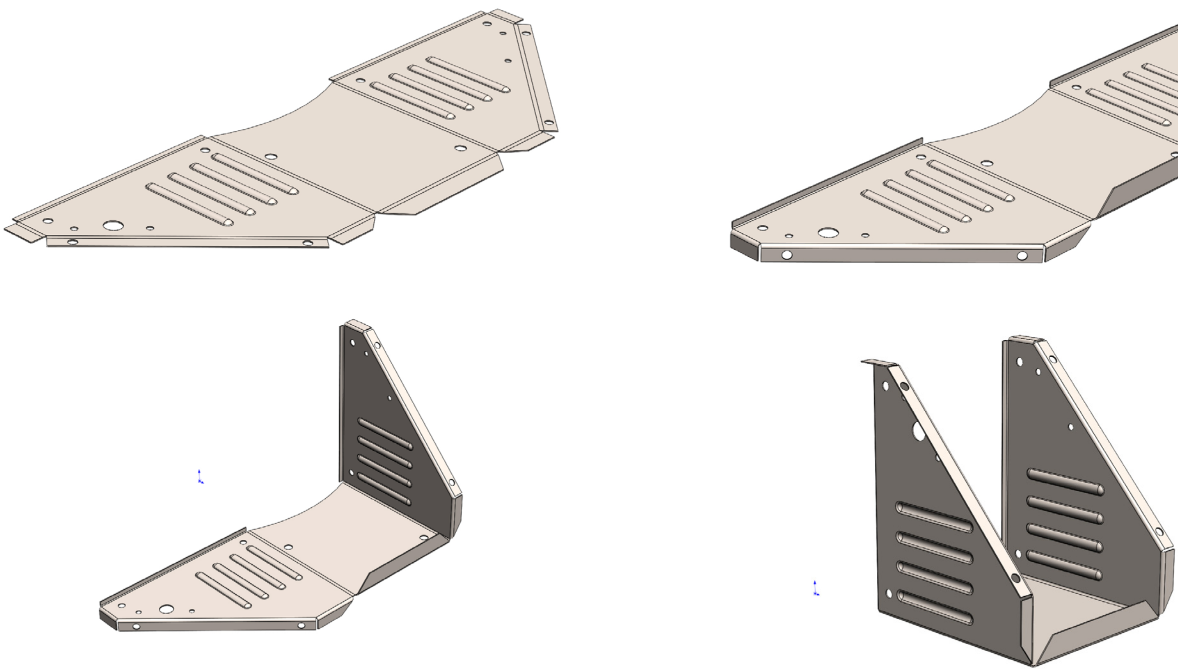


Image 7.3.27: Bending procedure of the electric storage box

Electric box lid

Image *7.3.28* below shows the folding steps of the lid. It is recommended for the lower bent to be bend slightly further to account for spring back and keeping pressure on the box when assembled for a good enclosure. Stiffness can be increased by adding a hem on the sides if proved necessary.

Image 7.3.28: Bending procedure of the electric box lid

7.3.11 Supplementary components

There are some components within the gasifier that need to be produced using a different production method than previously described. A short description of a suitable production method will be described in this paragraph.

Grade

The grade can be bought from a stock perforated sheet. The diameter of the holes should be 5 mm in order to prevent fuel from dropping through the holes. The entire piece can easily be cut with a blanking operation, but it can also be cut out with a drill.

Handle

For production of the handle the same thickness is used for the spacer as the handle. The handle could be made by making a complete circle with the radius of the handle. After the circle is bent pieces should be cut from 50 degrees, which produces 7 parts from each circle.

Turning operations

The reactor cap, the cap for the air tube and the air tube itself have to be produced by turning. A turning table can be both operated automatic and manual.

The air-tube can be cut to length from a standard Ø30 mm tube. Holes have to be drilled in after the turning operation.

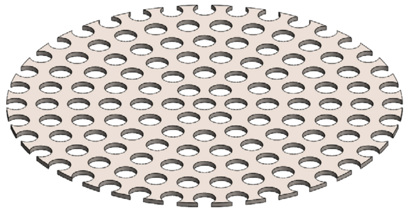


Image 7.3.29: Grade made from a pre-perforated plate

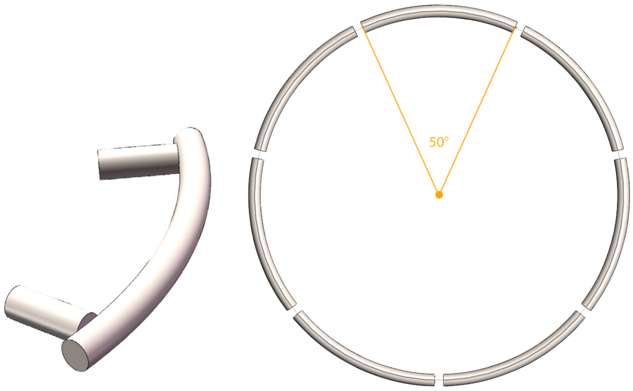


Image 7.3.30: Assembled handle cut from a circular bended solid tube

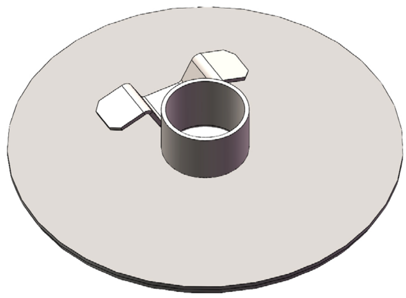


Image 7.3.31: Assembled reactor cap with universal clamp

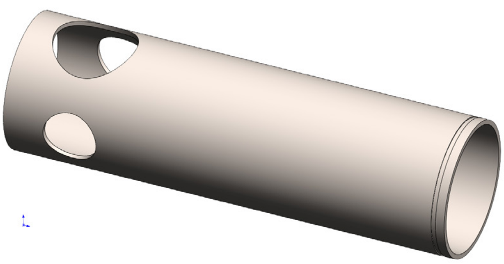


Image 7.3.32: Air-tube

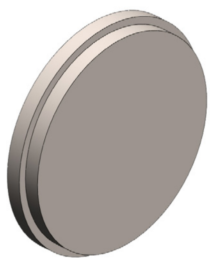


Image 7.3.33: Air-tube cap

Plier

The plier can be produce with a few bend operations. It is important that the plier keeps a constant tensions outwards so it does not snap out of the clamps inside the reactor when it is lifted out. The same material and thickness is chosen as a commonly used appliance for grilling. Wood insulation might be added if the plier gets too hot during use. However, it is assumed that this is not necessary.

Image *7.3.34*: Example of a commonly used grilling appliance

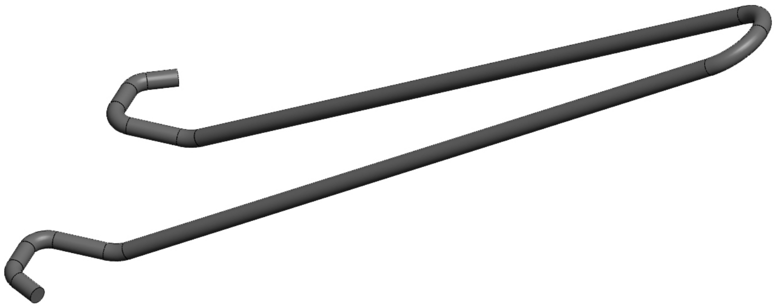


Image 7.3.35: Plier bended from a singular piece of metal rod

7.4 ASSEMBLY

For successful implementation of the gasifier it is important that besides the manufacturing steps, assembly of the product is also taken into account. Guidelines provided for manufacturing and assembly are aimed at optimizing the product so it can be produced efficiently and at a lower cost. Design for assembly (DFA) its primary concern is to reduce cost in the assembly. This can be done by implementing several commonly used strategies (Crow, 1998):

- Minimize the amount of parts to reduce the number of assembly operations (time reduction)
- Design parts with self-locating features
- Design parts with self-fastening features
- Minimize reorientation of parts during assembly
- Design parts for retrieval, handling, & insertion
- Emphasize 'Top-Down' assemblies
- Standardize parts
- Minimum use of fasteners
- Encourage modular design
- Design for a base part to locate other components
- Design for component symmetry for insertion or obviously asymmetrical

7.4.1 Sub assemblies

All the assembly steps are documented in appendix H.2. The assembly steps of the gasifier can be divided into eight sub assemblies:

1. The body
2. The inner tube
3. The reactor
4. The burner
5. The reactor cap
6. The air tube
7. The electronics
8. The Electro box

Te complete assembly requires 43 handling steps and is estimated to take 184 seconds. This would be possible if the assembly stages are well equipped and planned ahead. Looking at the context where the product will be produced, it is possible that it is done is a simple workshop with little space. An example is documented in appendix H.4 which shows the production of another stove in Vietnam. Image 7.4.1 below shows how a worker is surrounded by sub assemblies and assembled stoves.

Image 7.4.1: Stove manufacturing workshop in Vietnam

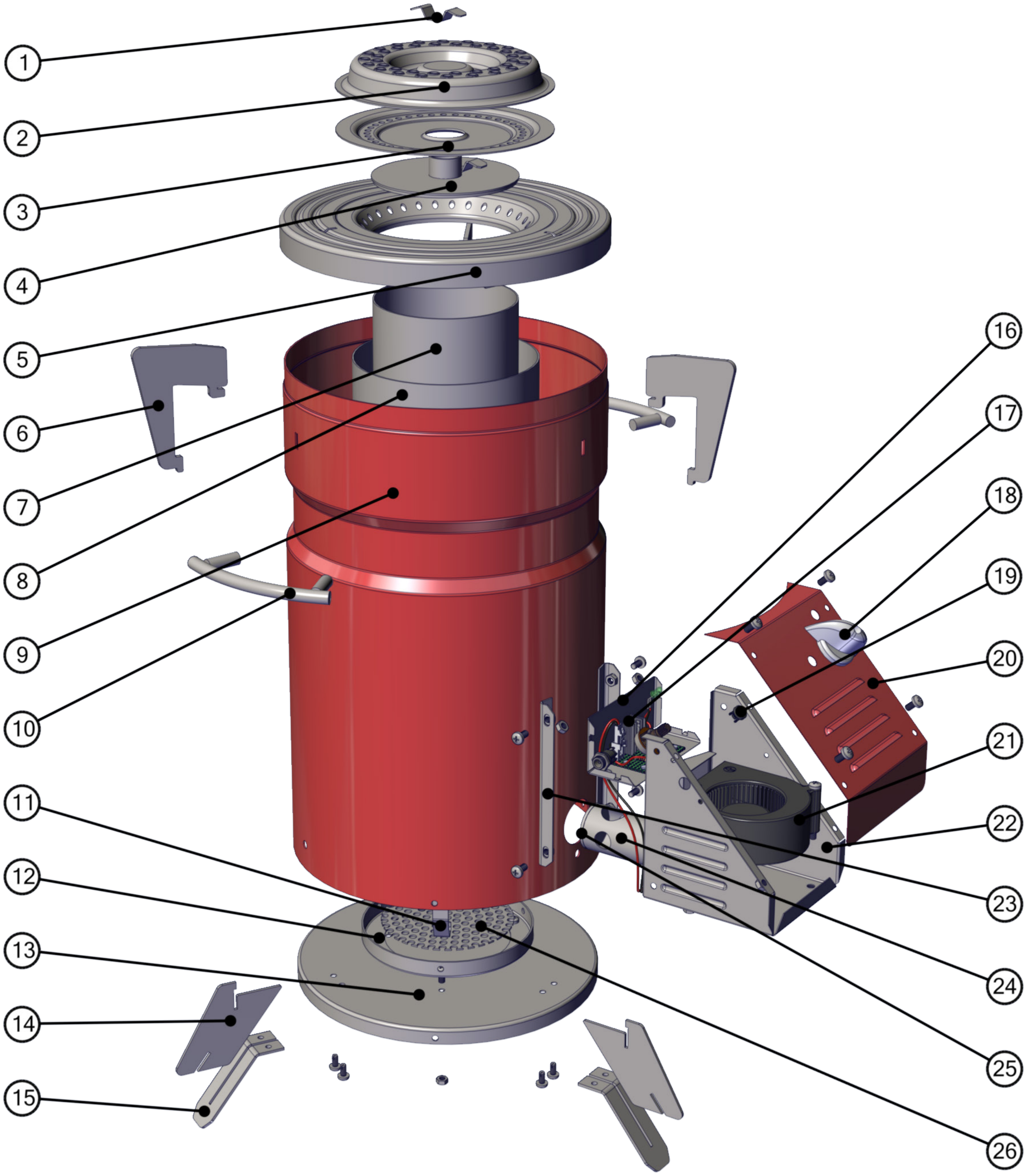


Image 7.4.2: Exploded view with part numbers

Part nr.		Part nr.		Part nr.		Part nr.	
1	Universal clamp 4x	9	Body	17	PCB + electronics	25	Air tube cap
2	Burner top	10	Handle 2x	18	Rotary switch knob	26	Grade
3	Burner bottom	11	Reactor holder 3x	19	Led holder	27	PCB spacer 4x
4	Reactor cap	12	Connection ring	20	Electric lid	28	Venturi tube
5	Top plate	13	Bottom plate	21	Blower fan	29	Blower connection
6	Pot support 3x	14	Feet vertical 3x	22	Electric box	30	M4X0.7X8 Screw 20x
7	Reactor tube	15	Feet horizontal 3x	23	Connection rail 2x	31	M4X0.7X35 Screw 2x
8	Inner tube	16	PCB tray	24	Air tube	32	M4 Hex nut 22x

Table 7.4.1: Part numbers with name

7.5 BUY-IN COMPONENTS

Some components have to be purchased from suppliers. This paragraph gives an overview of the buy-in components that are necessary for the stove. As investigated already a fan has been selected from a Chinese manufacturing partner. The other buy-in components consist primarily of electronics. As shown before it is possible to buy pre-assembled electrics for as low as $2.27. However, buying each component separately and manufacturing the parts at a local shop would only cost $1.19, this does not include labor costs. Prices of the components are retrieved from online marketplaces such as aliexpress.com and alibaba.com. It is assumed that the components are purchased in bulk to over 5000 pieces.

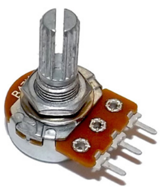
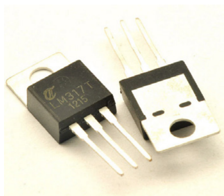
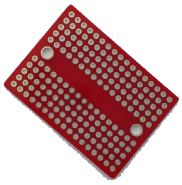
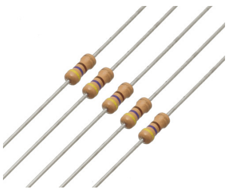
					
Fan blower	Potentiometer 10 K Ω	Rotary switch knob	LM317 voltage regulator	12 DC voltage jack	Led (red)
Price: $1 - $1.5	Price: $0.15	Price: $0.25	Price $0.55	Price: $0.06	Price: $0.03
A 75 mm flan blower	Should be mountable on the sheet metal lid	Available in different colors. Should have a 6.35 mm shaft hole.	For transferring the voltage signal to the fan	Should be mountable on the sheet metal box	A red LED with a 5 mm diameter
					
LED holder	PCB support clips	PCB	Resistors and capacitors	12 v power supply adapter	Assembled electronics
Price: $ 0.15	Price: $ 0.20	Price: 0.20	Price: $ 0.05/ piece -0.1 uF capacitor - 1 uF capacitor - 1 KΩ resistor - 2.2 KΩ resistor	Price: $1.03	Price: $2.27

Table 7.4.2: Overview of buy-in components

7.6 COST ESTIMATION

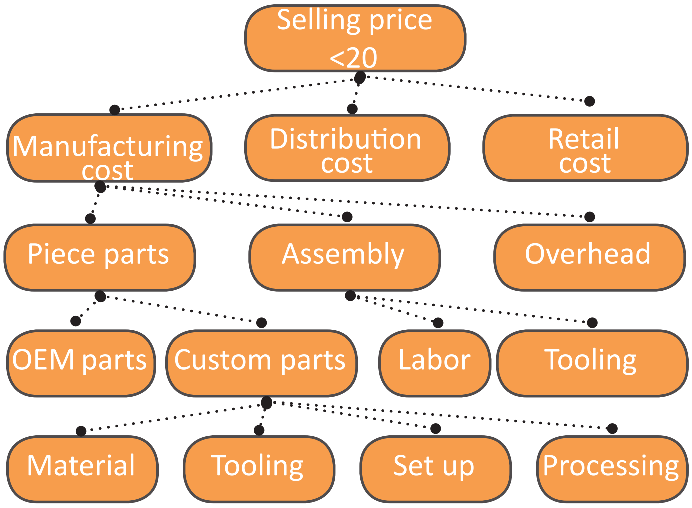


Image 7.4.3: Production cost analysis breakdown

The market which gasifier stove targets is highly cost sensitive. From a market research it was determined that the stove should not exceed a selling price of $20, with the target of $17 as stated in the requirements. Therefore, the manufacturing cost per unit should be no more than 9 USD.

7.6.1 Cost estimation from manufacturing partner

A cost estimation from a high quality production facility in Hanoi is presented in appendix H.5. In order to get the quotation they were provided with assembly drawings from an earlier prototype which was almost similar to the final design (appendix H.6). However, a lot of parts have been made thinner to reduce the material costs. Results from this quotation show that, for a production volume of a 50 000 pieces, they are able to produce one stove for 408 000 VND ($18.30). The total material costs were estimated to 180 749 VND ($8.10). Interesting is that they used the cheaper Stainless steel AISI201 in this estimation. They expect their tooling to last for 100 000 pieces before they need replacement.

A second price estimate of the final design will be made in order to evaluate the quotation and to provide a better understanding of how quotations are made in Vietnam. The chart presented in image 7.4.3 will be used to structure this estimation. First the focus will be on the manufacturing costs.

7.6.2 Manufacturing cost of custom parts

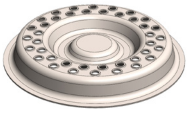
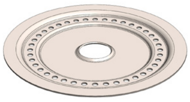
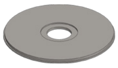
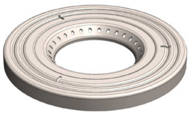
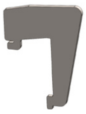
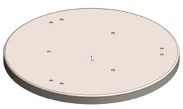
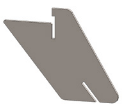
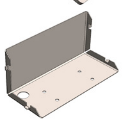
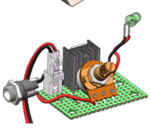
For this gasifier design most parts have a custom design and require investment in special tooling. It has been analyzed what the production steps are and what special tools should be invested in. Two experts on production and manufacturing in Vietnam have been approached in order to make an accurate estimation of the production cost.

Material

The material costs have been taken from the quotation of the supplier. For INOX steel SUS201 they used a steel price of 43 300 VND/ kg ($1.94/ kg). And for carbon steel JIS G3141 they used a price of 13 821 VND/ kg ($0.62/ kg). According to the production expert the higher grade of stainless steel 310 would cost around 70 000 VND/kg ($3.13/ kg). To calculate the material cost a percentage has to be accounted for as scrap, usually 10-20%. Therefore, the material cost per unit = part weight (kg) x scrap x material cost/ kg. In this analysis 15% is taken as an overhead rate for the scrap metal.

Processing

With most production facilities in Vietnam, the labor costs are not taken into consideration when giving a quotation. They give an estimation based on the amount of parts, material costs and complexity. Reason why hourly wages are not taken into consideration is because the average hourly rate is very low, just 20 000 VND ($0.90) per hour. Instead of the hourly wage, they can give you the price for each operation. For a stamp press machine the operations costs are 2000 VND ($0.09) per stamp including preparations and set up of the machine. It is assumed that the same amount can be applied to bending, punching and blanking operations. Based on the production analysis the number of operations per part is estimated. By knowing these parameters an estimate of the cost can be made.

Nr.	Picture	Part	Qty.	Mass (g)	Material	Nr. operations	Material cost unit ($)	Operation cost unit ($)
1		Universal clamp	4	3.5	Stainless steel AISI 202	4	0.007	0.36
2		Burner top	1	114.4	Stainless steel AISI 310	2	0.36	0.18
3		Burner bottom	1	106.6	Stainless steel AISI 310	2	0.33	0.18
4		Reactor cap	1	134.1	Carbon steel JIS G3141	2	0.08	0.18
5		Top plate	1	306.6	Stainless steel AISI 310	3	0.96	0.27
6		Pot support	3	55	Stainless steel AISI 202	1	0.11	0.09
7		Reactor tube	1	560.5	Carbon steel JIS G3141	1	0.35	0.09
8		Inner tube	1	895.61	Carbon steel JIS G3141	2	0.56	0.18
9		Body	1	1621.7	Carbon steel JIS G3141 + coating	4	1.01	0.36
10		Handle	2	58.3	Stainless steel AISI 202	4	0.11	0.36
11		Reactor holder	3	4.2	Carbon steel JIS G3141	3	0.003	0.27
12		Connection ring	1	64.5	Carbon steel JIS G3141	3	0.04	0.27
13		Bottom plate	1	296.9	Stainless steel AISI 202	3	0.58	0.27
14		Feet vertical	3	37.5	Stainless steel AISI 202	1	0.73	0.09
15		Feet horizontal	3	29.2	Stainless steel AISI 202	2	0.56	0.18
16		PCB tray	1	24.6	Stainless steel AISI 202	2	0.048	0.18
17		PCB + electronics	1	-	-	-	1.2/ piece	-

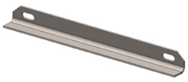
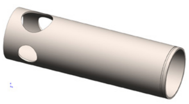
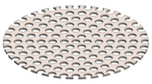
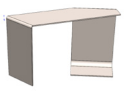
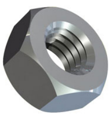
18		Rotary switch knob	1	-	ABS	-	0.25/ piece	
19		Led holder	1	-	ABS	-	0.15/ piece	
20		Electric lid	1	61.4	Carbon steel JIS G3141 + coating	3	0.04	0.27
21		Blower fan	1	-	ABS	-	1 / piece	
22		Electric box	1	98.8	Stainless steel AISI 202	3	0.19	0.27
23		Connection rail	4	18.0	Stainless steel AISI 202	3	0.035	0.27
24		Air tube	1	68.7	Stainless steel AISI 202	2	0.13	0.18
25		Air tube cap	1	20.6	Carbon steel JIS G3141	3	0.01	0.27
26		Grade	1	29.0	Stainless steel AISI 310	1	0.09	0.09
27		PCB spacer	4	-	Nylon	-	0.2/ piece	
28		Venturi tube	1	7.4	Carbon steel JIS G3141	2	0.005	0.18
29		Blower connection	1	6.7	Stainless steel AISI 202	2	0.01	0.18
30		M4X0.7X8 Screw	20	-	Stainless steel AISI 316	-	0.04/ piece	-
31		M4X0.7X35 Screw	2	-	Stainless steel AISI 303	-	0.04/ piece	-
32		M4 Hex nut	22	-	Stainless steel AISI 316	-	0.02/ piece	-
33		Insulation	1	40	Glass wool	-	0.6	-
Total material cost: **$ 9.99** Total unit cost with buy in components: $4.72 + $9.99 = **$14.71**								**$14.4**

Table 7.6.1: Material and processing cost estimation

Tooling

According to the production experts, the investment cost for making a stamp press mold from mild steel is about 250 dollars. The main cost driver of the mold is the complexity of the part and size. All the parts have been made cylindrical and symmetric. This has the lowest price for molds as it can be made by turning and other low cost production methods. From the production analysis it was determined that a total of eight molds was needed for the press forming operations, three for fine blanking and two for normal blanking and pressing of the electric box components. It is assumed that fine blanking requires a slightly higher investment cost for tooling due to the more complex shape. Regular blanking tooling costs would cost $200. The table below summarizes the total tooling cost.

Mold type	Nr of tools needed	Cost per mold ($)	Total ($)
Press forming	8	250	2000
Fine blanking	3	300	900
Blanking	2	200	400
Total investment cost for tooling			*3300*

Table 7.6.2: Tooling cost

Assuming that 5000 units would be produced it would add another $ 0.66 to the cost of the gasifier. For the manufacturing of lower production volumes these costs will increase and will be of more significant value in the total production cost. The choice to design the product in such a way that it could be produced with relative low investment costs makes it easier to start production of the stove.

7.6.3 Total cost of manufacturing

The final cost of the gasifier can be calculated by adding costs for assembly and any special treatments such as powder coatings. The estimated assembly time of just 184 seconds means that hourly wages will not add much to the total price of the product. However, the estimation did not take into account the time that is needed for coating and set up of the equipment. As the assembly line still has to be built it is assumed that 0.5 man hour is needed to produce one piece, which adds another $0.5 to the price.

Item	Price ($)
Total material costs	9.99
Overheat rate material cost (15%)	1.5
Total operation costs	14.4
Tooling costs/ unit	0.66
Total cost OEM parts	4.72
Total assembly costs	0.5
Coatings + treatments	1
Total cost of manufacturing	*32.18*

Table 7.6.3: Total cost of manufacturing

The total calculated cost for manufacturing is **$32.18**.

6.7.4 Final production cost

Beyond these, there are remaining costs that complete the retail price. The product must be put in a box for transportation. It must be transported to the stores and there are additional shipment cost from the OEM parts. These costs all need to be considered. This illustrates the complexity of giving a fixed answer to the retail price. However, as a general rule to account for the retail cost and distribution cost a 30% margin can be added to the cost. This would give a retail price of **$41.83** for a production volume of 5000 pieces.

6.7.5 Conclusion

The aimed retail price of 17 dollars has not been reached. Comparing the quotation received on the drawings of the earlier prototype the manufacturing partner aimed at much higher production volumes. Therefore, the price might be able to decrease but there is still effort to be done in reducing the price. By applying changes to the design such as part elimination, simplification of components and cheaper materials the price can be reduced. This will indefinitely influence the performance and lifetime of the product.

Therefore, a strategy like other stoves in the market can be adopted. This means targeting different segments in the western market as well as the developing markets. By doing this a different price can be asked and revenue can be made to drop the price in the lower income markets.

8 FINAL TESTING

8.1 FINAL PERFORMANCE TESTING

The main goal of this final test is evaluating the performance of the final design with the developed prototype. The stove was tested following the WBT 4.2.3 protocol procedure described in chapter 4.3.3. Three tests were executed in order to determine how efficient the stove uses fuel to heat water in a cooking pot. Besides this the quantity of PM2.5 an CO produced during the test was measured. The PM2.5 sensor that was used was low cost and was programmed using a arduino. The CO measurement device that was used failed to log the data. Therefore no graphs could be produced of this device. Only the average value was stored which could be monitored directly from the screen of the device.

The test describes three phases; a cold-, hot- and simmer -phase. For this test each phase uses a pot which is filled with 2.5-liters of water and starts with 450 grams of fuel. The complete test report is documented in appendix J.

8.1.1 results

Table 8.1.1 on the next page shows the results of the performance from the three test phases. The data was obtained by filling in the collected data of the test in the WBT_data-calculation_sheet_4.2.3.xls" spreadsheet.

The highest efficiency obtained was 67% during the hot start with a time to boil of 11 minutes. This is the highest results compared to all the other stoves from the market analysis in chapter 5.4. A lower thermal efficiency was obtained during the simmer test, but with 48% still qualifies as very efficient.

Image 8.1.1: Picture of the prototype taken on the TU Delft campus

Image 8.1.2: Test setup of the stove and measuring devices

1. HIGH POWER TEST (COLD START)	Units	Test 1
Time to boil Pot # 1	min	11
Temp-corrected time to boil Pot # 1	min	9
Burning rate	g/min	19
Thermal efficiency	%	57%
Specific fuel consumption	g/liter	54
Temp-corrected specific consumption	g/liter	45
Temp-corrected specific energy cons	kJ/liter	822
Firepower	watts	5.602

2. HIGH POWER TEST (HOT START)	Units	Test 1
Time to boil Pot # 1	min	11
Temp-corrected time to boil Pot # 1	min	9
Burning rate	g/min	16
Thermal efficiency	%	67%
Specific fuel consumption	g/liter	45
Temp-corrected specific consumption	g/liter	38
Temp-corrected specific energy cons	kJ/liter	684
Firepower	watts	4.889

3. HIGH POWER TEST (HOT START)	Units	Test 1
Burning rate	g/min	8
Thermal efficiency	%	48%
Specific fuel consumption	g/liter	123
Temp-corrected specific energy cons.	KJ/liter	2.223
Firepower	Watts	2.269
Turn down ratio	--	2.47

Table 8.1.1: Test results of the three test phases

8.1.2 Conclusion

The stove has excellent performance on thermal efficiency and can be ranked as TIER 4 on the performance scale. These tests were executed in good conditions with no wind, and at room temperature. Therefore, the results that were obtained might not be directly achieved by inexperienced users. The stove might operate inefficiently if too much power is provided by the flame for the needed task. All test results are highly dependent on the power level that is chosen. During the simmer test the flame was too powerful as it kept the water boiling during the entire test. A lower turn down ratio might increase the efficiency even further in this phase.

Looking at the PM2.5 during the operation there was almost no harmful smoke emitted. However, when the burner is not placed correctly (as the cold start test shows) in unventilated rooms it can be dangerous for users. High concentrations of produced gas will be expelled into the room. Therefore, users should be carefully instructed and trained.

8.2 DESIGN EVALUATION

The concept that is presented has a clear improvement compared the old prototype. Looking at the list of requirements most of the criteria have been met. However, there are some things that can still be improved.

Fuel

The burner of the gasifier should only be placed on top if a high enough temperature have been achieved and enough moisture of the fuel has been evaporated. Placing the burner on top too early makes it difficult to burn the produced gas due to the high amount of water vapor in the gas.

Usage

When a different fuel is used, other than pellets, there is a possibility that the moisture concentrations are too high for good gasification of the biomass. When this is true, the user should understand that the burner should not be placed on top. The stove can still be used without the burner.

Some parts of the gasifier can get very hot. Especially and the burner and reactor. Therefore, a special plier has been developed. However, the user should have a space available to place the hot burner somewhere safely when it is hot. Multiple times during tests someone got burned because the part did not cool down enough and tried grabbing it.

When the flame goes off during the operation, the user should know what to do to reignite the stove. Sometimes it is necessary to increase the fan speed as this will increase the temperature in the reactor.

Funnel

A good improvement of the gasifier is the addition of a funnel. This provides two advantages. The first is that it makes the gasifier suitable for more types of biomass as the secondary air creates a vortex in the center. Secondly, it makes filling of the gasifier easier as the fuel is guided into the reactor.

Performance

The performance of the gasifier is one of the best trademarks of this design. With a thermal efficiency of 67% it provides a very good performance. Improving the turn down ratio in the simmer mode, might increase the efficiency even further.

Context

It has been chosen to make the selected color for this concept not too obtrusive. The turquoise matches the polished steel components and does not form a big contrast with the black pot support and feet. The pot support has been coated black as this hades color changes due to heating after a few operations. Compared to other stoves in the market the cylindrical shape does not stand out on its own. However, the attached components has given the design a unique look.

Production

It has to be explored if the production of certain parts produces a lot of scrap metal. If this is the case a solution has to be explored to minimize this in order to decrease the material costs.

Technical drawings

A technical data package of the final design is presented in appendix K.

Image 8.2.1: A digital render of the final design

9 REFLECTION

9.1 RECOMMENDATIONS

Within the time that was available for this project, steps have been made towards a new and improved design for a micro-gasification cookstove. Most aspects of the product have been thoroughly analyzed and tested. Multiple design iterations have been made with the use of prototypes, until an optimal result was reached in terms of performance. The product is close to being ready for mass production but there are still some improvements that could be made for future developments.

Fan location
The fan could be placed at the bottom of the cookstove which would eliminate the need for the electric storage box and decrease the amount of components. This is also done in some of the competitor products on the market. However, this does provide design challenges of its own. Due to the heat of the burned fuel it would need multiple layers of insulation otherwise the heat could damage the electronics. These additional layers will decrease the available space for the reactor which makes the overall gasifier higher.

Injection molded parts
When higher production volumes have to be obtained and more budget is available for investment of special tooling, it can be chosen to make use of injection molded parts. The sheet metal components, especially for the electronic box, are a lot more labor intensive to produce. Even though labor wages are low, the benefits of incorporating fasteners in the components make both assembly and production a lot easier.

Sheet metal parts
Almost the entire product is assembled by the use of nuts and screws. The amount of fasteners can be decreased by making parts the clamping of one side and using a single screw on the other. Also semi-permanent fixtures such as pop rivets can be used as an alternative for screws.

Target markets
Looking at the different market segments it is advised that multiple versions of the gasifier should be developed to fit their specific context. The following specific stove characteristics can be added to fulfill the specific needs of that segment:

- A continues operated gasifier for industry, restaurants, street food vendors etc.
- A semi-continues gasifier for higher household demand or smaller street food vendors
- A portable electric generating/ rechargeable stove for street food vendors
- A portable (smaller) electric generating stove for camping and outdoor activities
- A very cheap electric generating stove for the poor and rural households

Material thickness
The thickness of the materials of the new design is different compared to the prototype. It has to be explored if some parts can be made even thinner, primarily no to decrease the material cost but to increase portability and transportation.

User testing
The new design has not been tested with the user yet. Although the functionality is a lot the same as the previous prototype of CCS there are some differences. The stove should get a coating with a desired color of the target market. Research should be done to gain insights in this preference.

Burner
The burner is optimized to increase the efficiency. However, it does require some skill of the user to operate the stove properly. The reactor cap and the burner are now placed individually, it should be explored how this can be done in one step to increase the usability.

9.2 PROJECT EVALUATION

The project assignment was clearly formulated: Design of a user friendly, safe and efficient biomass gasifier for Vietnamese households. This would be based on a lab prototype that was almost ready for mass production. Therefore, the new design should be, low cost, and produced using low investment mass production techniques. To reach this goal there were many challenges which had to be overcome in little under seven months. At the start of this project I did not expect the complexity of the project ahead.

The project started by identifying the issues of the lab prototype. This was needed to create a design focus for the project. It was reasoned that the company could provide technical drawings on their latest prototype. This could then be used for an analysis and optimizing it following the design for assembly (DFA) and design for manufacturing (DFM) guidelines. However, soon after the start of the project, it became clear that the company was still in the developing phase, rather than being close to production.

The start of the project was executed from the Netherlands. This required long distance communication between with the company. Misunderstandings were the cause of both cultural differences and lack of proper documentation. This can be illustrated with the following two examples. During the start information had to be gathered on measurements of the latest prototype and overall stove assembly. A test report, some pictures and a simple technical drawing were provided. However, the technical drawing was of a different prototype than the pictures. This made it hard to do any relevant work beforehand. It was also not communicated that they were still working on an new and improved prototype, which they finished in the first few days of my arrival in Vietnam. Had their efforts been communicated more clearly, more work could have been done beforehand.

Secondly the lack of understanding can be blamed on cultural differences. During one of the Skype meetings questions were asked about the cost estimation and aimed retail price of $17. They said that one of the components, the fan, was made entirely by themselves. It was thought that they just meant the housing or fixture of the fan. Because it was believed not to be true, for them to actually make such a stock component themselves. This misunderstanding was blamed on language issues. Though this seems irrelevant, it presents a clear example of two very different ways of thinking. For the Vietnamese, it represents their mentality towards their own production capabilities. They did not see any problem in fabricating a couple of 1000 units like this by themselves rather than just buy one from a mass production company. This taught me that working with Vietnamese colleagues during the project it requires keeping a constant focus on the end goal. Otherwise is was easy to get carried away in their enthusiasm of making everything and keep on developing rather then moving to actual production.

Looking back the decision was made to perform additional research towards the market and the user context. This was thought to be necessary as I was overwhelmed by all the other prototypes that had been made while thinking there would just be three of them. One pellet and two rice husk gasifiers of the previous graduate students. In hindsight it can be argued what additional value the identified primary user needs and all the market research contributed to the final design other than all the effort it required. It is difficult to tell what trades of the Vietnamese traditions have been physically translated to the final design. I would like to believe that it helped with the overall decision making process. If this step had not been done, more time would have been available for research on the implementation of the production line.

Concluding the evaluation, this project has had a close connection with all the domains of industrial design. Knowledge on human, business and technology has formed an important base for the successful completion of this project. By doing the project abroad, it has also improved my capabilities as an industrial designer to work in a different context.

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APPENDIX A: GRADUATION PROPOSAL

APPENDIX A.1: GRADUATION PROPOSAL

1.1 Introduction

Gasification of biomass for cooking purposes shows to be a promising solution for several health and environmental issues that occur with traditional methods of cooking in Vietnam. The combustion of the biomass produces a much higher thermal efficiency then the still popular, but very toxic, beehive coal. It is not strange that for this reason, gasification has already been explored widely by many different parties. Even though there are some good products and prototypes available, they did not prove to be successful in the market for many different reasons.

This project in particular has already been the subject of two former IDE graduates, who have already done a lot of research towards cooking habits, market analyses, user research and etc. This resulted in many different working prototypes which were constantly improved. Though the latest version of the biomass gasifier has been made by the company itself, they used the previous work of the graduates as input. This resulted in a newly developed gasifier with a 43% thermal efficiency. However, due to it still being a lab prototype the gap between the current state and a marketable product is still big.

One of the most common ways of cooking is with the earlier mentioned beehive coal briquette. But because of the health and environmental issues that come with it, the government plans to eliminate the beehive coal within the next 5 years. This created a lot of recent attention towards a gasifier cookstove. However, because current cookstoves in the market are not able to fulfill all the primary needs of the end user, it still struggles with low adoption rates. (GHTC 2014)

The primary user needs that have to be identified are listed below:

1. Fuel savings
- Is the amount of fuel currently needed adequate for the cooking task?
- How much fuel is currently being used for the different cooking tasks?
- How much fuel is being saved by using the gasifier and thus how much money do they save compared to old cooking methods?

2. Flexibility with different types of fuel
- What types of fuel are available in the target market its region?
- Which types of fuel can be used?
- Which types of fuel does the user want to use?
- What are the chemical compositions of the fuel used for the gasifier cookstove? (Needed for calculations)

3. Reduction in emissions
- What are the acceptable values of toxic gases emitted during the cooking process?
- Is the emission currently expelled within acceptable boundaries?

4. Cooking time
- Are the end users satisfied with the speed of the current cooking process?
- What time is acceptable for boiling 3 liters of water?
- What are the demands for regulating the turn down ratio?

5. Local food preparation
- What are the user's customary cooking practices?
- Is the gasifier cookstove compatible with the user's customary cooking practices?

6. Compatibility with local cooking equipment
- What local cooking equipment is being used?
- Is the current prototype compatible with this equipment?

7. Maintenance
- Does the current prototype need a lot of maintenance for it to function well?
- How much maintenance is expected of the user to do by them self?
- How hard it to do the maintenance that is needed?

8. Ease of use
- Can the current prototype be left unattended?
- Does the user know what to do if the flame is unstable, yellow (incomplete combustion)

9. Aesthetics
- Do current cookstove designs appeal to the consumers?
- What does the end user consider as aesthetically pleasing within household products?

10. Affordability
- How much are the end users willing to pay for a gasifier stove?
- What do they expect from the cookstove considering the amount of money they pay for it?
- How much is the user willing to pay for a well-functioning gasifier cookstove?

11. Safety
- Is the gasifier cookstove safe in use?
- What parts of the cookstove can be improved regarding its safety?

Detailed design phase and production
By identifying the different primary user needs and implementing them into a new design it is expected that this will increase the adoption rate. Because only few companies have made an actual attempt to put their product on the market, it is also expected that this step will present new challenges.
The company CCS
The project will be in collaboration with CCS, Centre of Creativity and Sustainability located in Hanoi. This company was established from the SPIN (Sustainable Product Innovation) project. Their mission is to become a leading R&D, consultancy and capacity building organization in the field of sustainable consumption and production in Vietnam.

1.2 Problem definition

At this moment, most of Vietnamese households still rely on fossil fuels. This is due to most of the alternatives being too expensive as well as current gasification-stoves not meeting their primary needs just yet. This is due to the technical limitations: difficult to use, low efficiency, high cost, low reliability; but also, from a design perspective, because of the lack of comprehensive understanding about the user behavior and their needs.
CCS has developed a promising prototype of a gasifier cookstove that runs with wood and rice husk pellets. However, the gasifier still needs improvement with the challenge of bridging the gap between a lab prototype and a commercialized product.

1.3 Assignment

Bridging the gap between a lab prototype gasification stove and a commercialized product. By fulfilling and implementing the primary user needs into a final design.

1.4 Approach

Because there is a lot of information available about gasification and culture studies towards cooking habits have already been explored it is not necessary to do this all over again. Instead using the information that is available and spend this time on design optimization and design for manufacturing. Experience and research show us that a lot of projects executed in BoP (Base of the Pyramid) environments, end with a nice prototype or product and even advice on how the product could be produced and what possible sales and distribution channels could be used. Though this can be useful, small companies often lack the knowledge or resources to execute this phase. That is why this assignment will focus on filling this gap between prototype and a commercialized product.

Step 1 Research phase
- Model the current prototype in SolidWorks for analysis
- Define the primary user needs by answering the questions presented.
- Formulate a list of requirements based on the primary user needs.
- Identify problems with the current prototype by testing it against the list of requirements.
- User testing
- Provide solutions for the know issues of the gasifier prototype.
- Implement findings on solutions into a new prototype.

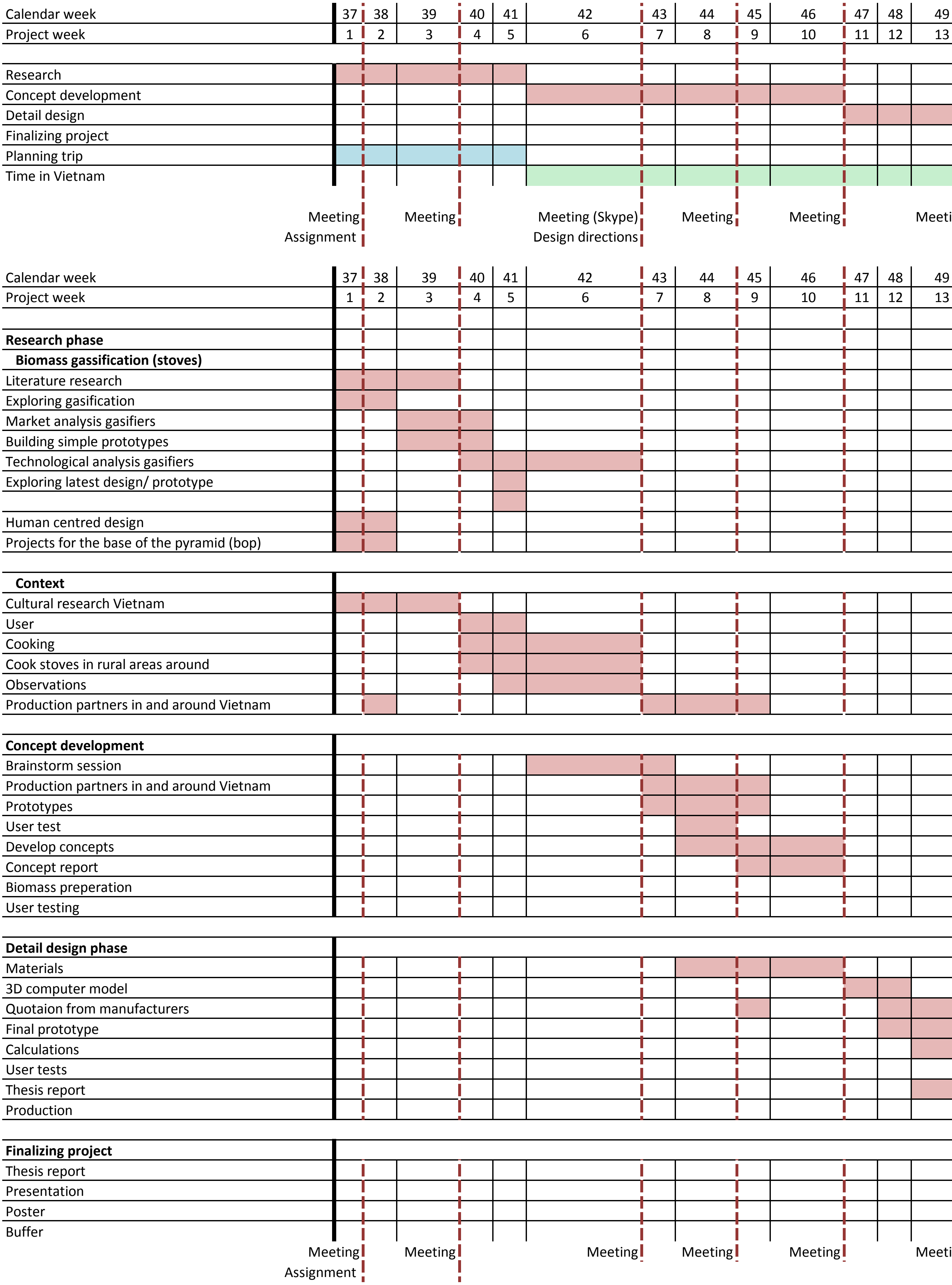
Step 2 Concept development phase
- Perform user tests with the new prototype and test how well it fulfills the primary user needs.
- Improve the prototype on findings from the user test.
- Optimize design for manufacturing and lower production costs.
- Optimize design for assembly/ maintenance with a modular approach.

Step 3 Detail design phase
- Update CAD model and technical data package
- Define specific materials
- Contact suitable production partners locally
- Investigate distribution channels
- Start producing first batch to test in the market

1.5 Goals

The goal of the project is to deliver a gasifier stove design that is ready for mass production. The stove itself will be based on the current prototype but will be improved regarding its user-friendliness, safety and price.
The new gasifier should:
- Fulfill the primary user needs
- Designed to be produced in mass production
- Being able to sold for an affordable price

1.6 Planning


Calendar week
37 38 39 40 41 42 43 44 45 46 47 48 49
Project week
1 2 3 4 5 6 7 8 9 10 11 12 13
Research
Concept development
Detail design
Finalizing project
Planning trip
Time in Vietnam
Meeting
Assignment
Meeting
Meeting (Skype)
Design directions
Meeting
Meeting
Meeti
Calendar week
37 38 39 40 41 42 43 44 45 46 47 48 49
Project week
1 2 3 4 5 6 7 8 9 10 11 12 13
Research phase
Biomass gassification (stoves)
Literature research
Exploring gasification
Market analysis gasifiers
Building simple prototypes
Technological analysis gasifiers
Exploring latest design/ prototype
Human centred design
Projects for the base of the pyramid (bop)
Context
Cultural research Vietnam
User
Cooking
Cook stoves in rural areas around
Observations
Production partners in and around Vietnam
Concept development
Brainstorm session
Production partners in and around Vietnam
Prototypes
User test
Develop concepts
Concept report
Biomass preperation
User testing
Detail design phase
Materials
3D computer model
Quotaion from manufacturers
Final prototype
Calculations
User tests
Thesis report
Production
Finalizing project
Thesis report
Presentation
Poster
Buffer
Meeting
Assignment
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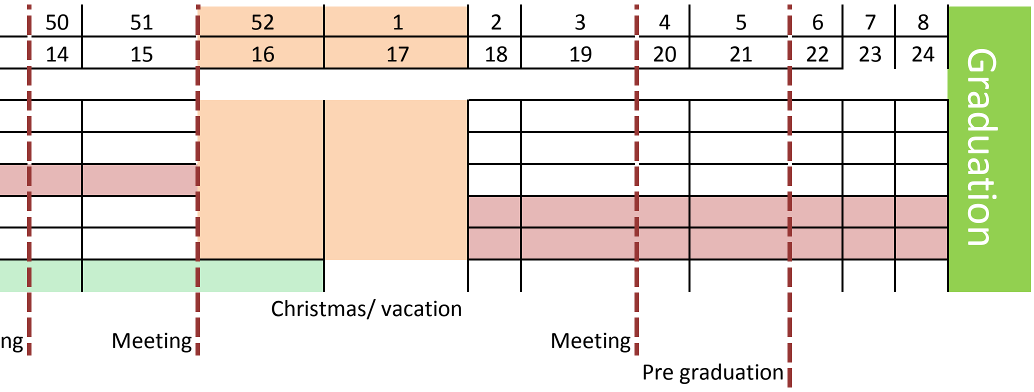
50 51 52 1 2 3 4 5 6 7 8
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Graduation
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Meeting
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Pre graduation


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Graduation
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Meeting
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Meeting
Pre graduation

APPENDIX B: INTRODUCTION

APPENDIX B1: NEWS PAPER ARTICLE NRC NEXT

.buitenland 14

HOUTVUURTJES BINNENSHUIS

Koken eist vijf keer zo veel levens als malaria

FOTO ROBIN UTRECHT/CORBIS

Overal in arme landen koken mensen binnenshuis op vaste brandstof zoals hout of gedroogde mest, met **longziekten** tot gevolg. Deze foto is gemaakt in Ethiopië.

Kooktoestellen in arme landen kunnen levens redden. En ze zijn ook nog eens goed voor het klimaat. Nederland moet ze daarom blijven financieren, bepleiten ngo's en bedrijven.

Door onze redacteur
Paul Luttikhuis

AMSTERDAM. Cookstoves kunnen een belangrijke bijdrage leveren aan het voorkomen van klimaatverandering en kunnen miljoenen levens redden. Met de financiering van deze zuinige, schone kooktoestellen in ontwikkelingslanden kan Nederland volgens Sible Schöne, programmadirecteur van het HIER Klimaatbureau, eenzelfde rendement bereiken als met de klimaatdoelen in het Nederlandse Energieakkoord, bedoeld voor de omslag naar duurzame energie. Voor nog geen tiende van de kosten.

In een brief aan de Tweede Kamer pleiten dertien organisaties en bedrijven, variërend van Philips tot Hivos en het FairClimateFund, er daarom vandaag voor dat Nederland doorgaat met het financieren van projecten voor schoner koken. De organisaties willen tot 2020 in ontwikkelingslanden tien miljoen kooktoestellen verspreiden. Maar de huidige projecten worden nog betaald uit de 500 miljoen euro extra ontwikkelingsgeld voor duurzame energie van het kabinet-Balkenende IV (CDA, PvdA, CU) uit 2007. En die pot, waarvan zo'n 100 miljoen euro naar kooktoestellen ging, is in 2017 leeg.

Gedroogde mest

Volgens Wim van Nes, van ontwikkelingsorganisatie SNV, koken wereldwijd circa 2,9 miljard mensen op 'vaste brandstof'. In steden is dat vooral houtskool, op het platteland veelal hout of gedroogde mest. Bij de verbranding daarvan komt veel roet vrij en zo wordt koken een ongezonde bezigheid. „Zo'n simpel houtvuurtje binnenshuis wordt ook wel *the silent killer in the kitchen* genoemd", zegt Van Nes. „Volgens de Wereldgezondheidsorganisatie sterven jaarlijks meer dan vier miljoen mensen aan longaandoeningen door het koken op hout." Dat is het vijfvoud van het aantal doden dat malaria eist.

De cookstoves zijn er in soorten en maten. Maar voor alle varianten geldt dat ze veel minder brandstof nodig hebben en dat de brandstof optimaal wordt benut. Dat betekent dat cookstoves niet alleen goed zijn voor de gezondheid van de gebruikers, maar ook kan helpen om houtkap en bosdegradatie te voorkomen. Ook kunnen vrouwen - en vaak ook kinderen - meer tijd aan andere dingen besteden, omdat ze anders uren bezig zijn met het sprokkelen van hout.

> De houtvuurtjes worden ook wel *the silent killer in the kitchen* genoemd

Daarnaast zijn de cookstoves goed voor het klimaat. Een gemiddeld apparaat bespaart 1,2 ton kooldioxide per jaar. „Dat is ongeveer net zo veel als tien zonnepanelen", zegt Schöne. „En dat voor maar een paar tientjes per jaar." De tien miljoen kooktoestellen die de ontwikkelingsorganisaties tot 2020 willen financieren, leveren dus een besparing op van bijna 12 megaton CO_2: 5 procent van de totale Nederlandse uitstoot van broeikasgassen. En dat voor enkele tientallen miljoenen euro's. „Ter vergelijking, het Energieakkoord levert 13 tot 17 megaton CO_2 op", aldus Schöne.

De doorbraak voor de zuinige kooktoestellen kwam volgens Wim van Nes een jaar of vijf geleden. De eerste projecten verliepen vaak moeizaam. „Dat kwam door de afwezigheid van het bedrijfsleven", zegt Van Nes. „Veel aandacht ging naar het product zelf. Terwijl die juist gericht zou moeten zijn op de markt."

Maar ook nu blijven volgens Van Nes genoeg uitdagingen over. „Het belangrijkste is dat de lokale bevol-

UITKOMST VOOR HET DORP

Als het over de cookstoves gaat, lichten ieders ogen op

De zes kinderen van Memuna uit India hoesten minder, nu hun moeder een schoon kooktoestel heeft. En ze houdt tijd over: sprokkelen is zo gebeurd.

Door onze correspondent
Joeri Boom
BERAA ALI MUDDIN

Op een pleintje in het dorp Beraa Ali Muddin, bij het kantoor van het dorpshoofd, zit een groepje van zo'n twintig mannen. Sommigen zitten op touwbedden, anderen op de grond. Op het gebouw hangt een groot plakkaat waarop wordt uitgelegd dat het dorp deelneemt aan een experiment voor 'geïntegreerde huishoudelijke energie', gesubsidieerd door de Indiase overheid.

Herhaal die woorden, en de mannen - van wie velen niet kunnen lezen - begrijpen niet waar het over gaat. Maar vraag hun naar de *cookstoves* en hun ogen lichten op. Trots kijken de mannen toe hoe een vrouw op zo'n verwarmer thee bereidt voor de gasten die uit de hoofdstad New Delhi, uren rijden van hier, naar hun afgelegen dorp zijn gekomen.

De cookstove is een aluminium kookstel waarin takjes, bladeren en andere biomassa worden verbrand. Aan de onderkant is een kleine ventilator gemonteerd die in een eerder leven werd gebruikt om een computer te koelen.

„De wanden van de stove zijn hol", legt Ram Lal uit. Hij is onderzoeker bij het instituut TERI, en meegekomen uit New Delhi. „Daardoor kunnen we er lucht doorheen jagen met de ventilator. Door de gaatjes in de wand wordt de vlam opgestuwd." De cookstove gebruikt daardoor veel minder energie dan de normale kleioventjes. Met een brede lach onder zijn grote bril maakt het dorpshoofd kenbaar dat de thee klaar is. Veel sneller dan jullie hadden gedacht, hè, zegt zijn vriendelijke grijns.

Memuna (25) heeft zes kinderen. Ze is de hele dag aan het koken om ze te voeden. Twee jaar geleden haalde ze haar man over om aan het project mee te doen. „Koken gaat nu sneller. Maar ik vond het vooral belangrijk dat er minder rook vrijkomt bij de cookstoves", zegt ze. Onderzoeker Lal legt uit dat de zeer hete vlam bijna alle biomassa verbrandt en vrijwel niets omzet in roetdeeltjes. „Dat is veel minder ongezond". „Nu hoesten mijn kinderen minder en hebben we geen last meer van onze ogen", zegt Memuna.

Het dorp is niet aangesloten op het elektriciteitsnet. Boven op haar huisje, opgetrokken uit steen met een dak van takken, staat een klein zonnepaneel van zo'n 60 centimeter bij 1 meter. Dat wekt de energie op die nodig is om de ventilator onder in de cookstove aan te drijven. De stroom wordt opgeslagen in een batterij. Naast de ventilator kunnen er ook twee ledlampen mee worden gevoed. „En we kunnen nu altijd onze telefoons opladen, want er zit een oplaadsnoertje aan vast", zegt Memuna. „Mijn kinderen kunnen veilig 's avonds hun schoolwerk doen. We hoeven niet bang te zijn voor brand door de kerosinelamp."

Afval als brandstof

Het project is inmiddels ten einde. Memuna wilde de stove graag houden, want er waren nog meer voordelen dan het snelle koken en de afwezigheid van prikkende rook. „We nemen afval mee van ons land als brandstof. Stengels, bladeren. Dat is genoeg om een avond mee te koken. Ik hoef niet apart meer op zoek naar hout." Onderzoeker Lal: „Dat scheelt haar tijd, en het scheelt India kaalslag. Minder sprokkelen is minder bodemerosie."

Wie de cookstove na het project wilde blijven gebruiken, moest er een aanschaffen. Een volledig systeem kost 10.000 roepies (135 euro), inclusief cookstove en zonnepanelen. Als de overheid het niet zou subsidiëren, zou dat zo'n 15.000 rupees zijn. Memuna haalde haar man over in de buidel te tasten. „Ik heb daar geen spijt van", zegt hij lachend, met de armen over elkaar.

Haar man heeft geen spijt van de aanschaf van 150 euro

„Iedereen in het dorp wil een cookstove hebben. Kunt u daar niet voor zorgen?", vraagt het dorpshoofd aan onderzoeker Lal bij vertrek uit het dorp. „Dat vraagt hij me telkens als ik hem ontmoet", zegt Lal als we het dorp uitrijden. „Maar er zit een grens aan de staatssubsidie."

Het merendeel van de inwoners van Beraa Ali Muddin is arm. De meesten kunnen zich de cookstove niet veroorloven. Van de duizend gezinnen in het dorp hebben er 150 een cookstovesysteem met zonnepaneel aangeschaft.

Cijfers
Grote klimaatwinst

2,9 mld
mensen koken binnenshuis op houtvuurtjes, met ernstige gevolgen voor de gezondheid.

4,3 mln
mensen sterven volgens de Wereldgezondheidsorganisatie voortijdig door het koken op hout.

60 mln
dollar heeft Nederland in 2014 toegezegd als bijdrage in vier jaar voor schoon koken. Het geld gaat naar de internationale organisatie Global Alliance for Clean Cookstoves die tot 2020 100 miljoen cookstoves wil verspreiden. Dertien Nederlandse organisaties willen er daarvan tien miljoen voor hun rekening nemen.

12
megaton kooldioxide zou door die Nederlandse bijdrage in 2020 ongeveer minder worden uitgestoten.

1 miljoen
cookstoves hopen de Nederlandse organisaties via zogeheten *carbon credits* te financieren. Dat zijn bijdragen van particulieren die hun eigen vervuiling (zoals door vliegvakanties) willen afkopen door elders uitstoot te reduceren.

king de voordelen gaat zien. Daarvoor moeten mensen oude gewoontes loslaten. Het is net als met sanitatie. Mensen moeten eerst begrijpen dat het niet verstandig is hun behoefte in de openlucht te doen."

Het ministerie van Buitenlandse Zaken wil niet vooruitlopen op een onafhankelijke evaluatie van de projecten die met de 500 miljoen euro aan ontwikkelingsgeld zijn gefinancierd. Het rapport komt volgende maand en wordt, met een aanbeveling van het ministerie, naar de Kamer gestuurd.

De verwachting is dat het ministerie de voordelen van deze vorm van ontwikkelingssamenwerking wel ziet. Net als andere landen heeft Nederland beloofd bij te dragen aan klimaatfinanciering voor arme landen. Daar passen de cookstoves goed in. Het helpt dat ze direct de levens verbeteren van de allerarmsten. Want juist daarop is het beleid van minister Ploumen gericht.

FOTO SNV

Cookstoves, zoals dit exemplaar bij een gezin in Laos, zijn aluminium kookstellen waarin biomassa wordt verbrand.

APPENDIX B.2: VIETNAM OVERVIEW

The project will be executed in a different context compared to the western market. This chapter is dedicated to exploring Vietnam and gives a short overview on the different cultural factors that might be important in a later stage when important design decisions have to be made. During the three months in Vietnam both the mountainous regions and the coast in the north have been explored. It is no surprise that the landscape is breath taking and unique. At the same time, it shows that living in the countryside forms a big contrast to living in a big city such as Hanoi. This chapter will explore the macro environmental characteristics of Vietnam.

Image B.2.1: Mountainous view in Sapa, Vietnam

Social

What is the country demographics & population distribution across regions?

Looking at the statistics presented in the table B.2.1 on the right, Vietnam its population is still largely rural (almost 71% of the population). However, it is quickly becoming one of the largest middle income countries. There total population is over 90 million who are living in approximately 23 million households. Over 16 million of them have risen out of poverty since 1998. While the population is still very rural, an increasingly richer population has high aspirations and expects a higher level of performance from their household products.

Population Demographic	Vietnam
Total Population (2014)	90,730,000
Population Growth Rate (CAGR)	1.1%
Rural/Urban Split (%)	71% / 29%
Rural Population	61,898,763
Total Households	≈22,628,000
Rural Households	≈15,826,985
Average Household Size	3.8
Literacy – Total (%)	94%
Literacy – Female (%)	92%
Life Expectancy (years)	76 (2013)
Access to non-solid fuel rural 2012	35.8
Access to non-solid fuel urban 2012	83.9
Population below poverty line	13.5% (2014)

Table B.2.1: Vietnam demographic population statistics. (Databank.worldbank.org, 2016)

Gender

How does gender play a role in clean cookstove use and purchase?

The financial decision is often handled by the male head of the household and since women and children are the ones that are cooking an investment in an advanced cookstove might not be prioritized. Reduction in workloads for women and children in cooking and fuel collection as well as reduction in time spent cleaning cooking pots and tending the stove can be achieved by women through gasification, but might not be perceived as benefits to them.

Political Environment

How stable is the government & what political risks will clean cookstoves programs face?

While Vietnam is a communist state with a top-down governance approach, it is becoming increasingly decentralized. The country is divided into 64 provinces with 15 cities. Geographically Vietnam can be divided into three regions, the north, the middle and the south. They are differently influenced by history which reflects back in today's traditions such as the way of cooking and living.

The president is elected by the national assembly from among its member every five years. The communist party of Vietnam is the only party recognized by the government.

Partnership with a cooperative government agency (national as well as local) is critical to navigating the complex political and regulatory environment of Vietnam. It is critical for a successful rural program to have both national and local government cooperation, though it is not necessary for the government to fund or spearhead the initiative.

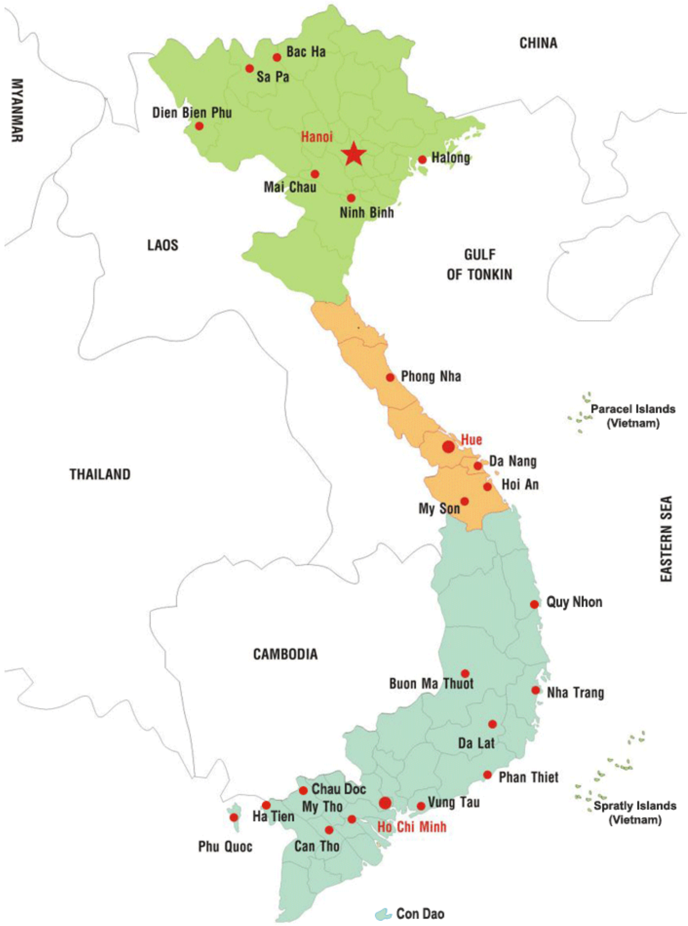
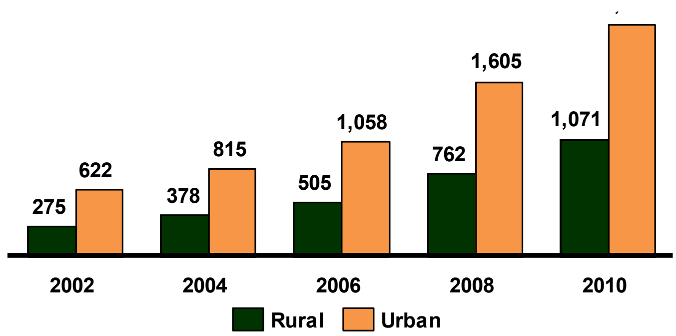


Image B.2.2: Map of Vietnam, divided regions of the north, the middle and the south.

Economic

How much money do potential customers have & what is the economic cycle?

As it has been stated Vietnam is growing quickly, it is moving itself up the ranks to a lower -middle income country. In the table on the right it can be seen that from 2002 the rural income per capita increased 19% and for the urban population 17% by 2010.



Graph B.2.1: Monthly average income per capita in Vietnam divided by rural and urban citizens.

Ecological environment

Vietnam its climate is of a tropical monsoon type, with the summer being hot and rainy and winters being dry and humid. The north is mountainous whereas as the south is hot and flat as it is much closer to the equator.

There is a lot of attention from governments and other investment parties for cookstoves and their role in reducing greenhouse gases and deforestation. This is important to keep in mind when applying for funding or when considering what they find important.

Hanoi

This project was primarily executed from Hanoi where the CCS is located. Several trips were made to areas outside the city to explore other contexts in which the gasifier could operate in. This page will describe my experience in this massive city.

A first impression of Hanoi can be described from an outsider as chaotic, I remember getting out of the taxi from the airport and was dropped right in the middle of it all. Motorcycles and cars honking and people constantly on the move. After living there for a while you start to see that there is some structure to it and adapt to eventually see yourself becoming one of these crazy drivers yourself.

Hanoi is very much a growing city, everywhere you look you will see constructions on either new buildings or renovating old ones. People living in Hanoi keep a lot of their traditions, this can be seen by the clothes they wear (such as the typical conical hat), or the food they eat. Life is lived on the streets, meaning that most people eat outside on the streets or mingle themselves at small street “cafés” to enjoy a beverage.

Image B.2.3: French style house in Hanoi

Image B.2.4: Construction work in Hanoi

Image B.2.5: Common view of a demolished sight

Modernization is also very much present everywhere you look. Almost everybody transports themselves and their goods with a motor bike. It is the most convenient way of traveling around especially in the city. There are high taxes on cars, they are not that abundant yet as only the very rich can afford them. For example, second hand imported cars with 1000 cc are subject to a 5000 USD tax for stronger engines this fee is doubled, and this is not even the only tax. There are some big supermarkets in the cities but the majority of the Vietnamese people buy their groceries fresh from the local markets or other street vendors. Supermarkets are more expensive and might gain more popularity when the income of the people increases.

Average hourly wage of construction workers and manufacturers is around 25,000,000 VND per hour. This means that living in Vietnam is also cheap in comparison. A typical dish with fresh noodles, meat and vegetables only costs you about 25,000,000 VND (1,2 USD). History plays an ever important role in the lives of Vietnamese people. During group conversation the subject will come up as part of the discussion. Politics and future ambitions are also hot topics, this shows the mentality of Vietnamese people striving for a better future.

Image B.2.6: Women walking with a Yoke selling food

Image B.2.7: Transportation of goods by bike

APPENDIX B.3: PREVIOUS GRADUATION STUDENTS

Rob's gasifier Design

Rob his graduation project finished in 2012 and was the first student to work with CCS (called the SPIN project at the time). From readings of Rob's graduation report it is clear that his design focused on improving the stove's performance in terms of combustion quality. The produced flame is clean with very little emissions. This can be seen in image *B.3.1* below, where the gasifier produces a blue color flame indicating complete combustion. This is also partly due to the fact that rice husk is used as biomass fuel, it is much harder to produce this combustion quality with wood pellets. This is explained more in depth in chapter 5.5. The main findings from this project are summarized below:

Calculations

An important part of his thesis is dedicated to the optimization of the combustion of the fuel, based on calculations and the theory behind gasification. Unfortunately, because his gasifier focused on rice husk the results do not directly apply to a wood pellet gasification.

Burner design

A lot of attention went to the design of the burner in order to improve flame stability and efficiency. This theory can be used in order to improve the design of the current prototype.

Prototype

Unfortunately, Rob his gasifier was not available for testing as it was not in the possession of CCS or TU Delft. Therefore, information about the performance relies on his graduation thesis and the experience of CCS employees with the stove. It was told by CCS employees that after some usage the tube of the stove under the burner got clogged. Tar built up as the secondary was not preheated it cooled down the primary air rapidly and could not burn completely.

Image B.3.1: Gasifier designs of previous graduate student Rob at CCS in 2012

Image B.3.2: Close up of the flame generated with Rob his gasifier

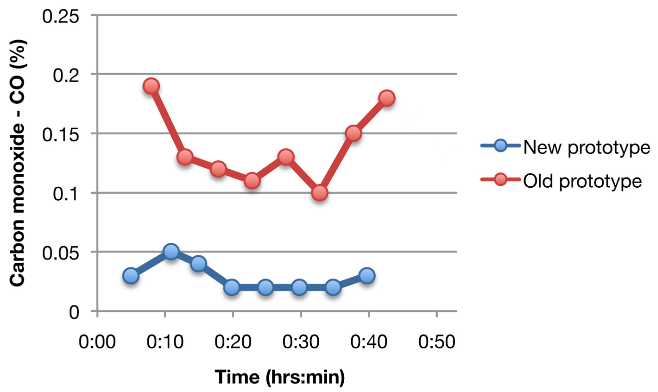


Image B.3.3: Improvement in combustion comparing old prototype with Rob his new design

Joan's gasifier design

Unlike Rob, Joan took a less technical approach in terms of advanced calculations. His approach was to use a human centered design. This meant that his focus was less on performance but more on usability and fitting the gasifier to the user context. The main findings from this project are summarized below:

Instructional sheet

To operate a gasifier safely clear instructions are important. Joan made an instructional sheet with three steps of operation. Loading, troubleshooting and unloading. This sheet could be modified to fit the new wood pellet gasifier design.
A reason why this is an important contribution can be explained by the following example. If the flame goes off at the top, highly toxic syngas is being generated and emitted in the air, this can be very dangerous for the health of the user. Another reason to choose for a sheet attached to the side could be because people rarely read manuals or do not have them at hand when they need it. It could also improve the aesthetics of the product.

Pot support

As part of the user centered design approach, different cooking equipment used by Vietnamese households were investigated. Dimensions of this equipment help when designing the pot support of the gasifier stove to fit the Vietnamese market.

The design of the pot support is made very cheap, which is important within this project. It consists of three pieces which can easily be cut from sheet metal plates. Three support structures provides good stability. Even when something is put on top which is not perfectly aligned it will always provide stability.

User context analysis

The context in which the gasifier has to operate has been mapped in high detail. Social structures and habits are clearly visualized for the rural population. However other market segments still have to be investigated.

Prototype

There have been 12 prototypes produced of Joan his design and tested in the field. Conclusions of these tests show that improvements can be done regarding combustion quality, usability, cabling and flame stability.

Image B.3.4: Gasifier designs of previous graduate student Joan at CCS in 2012

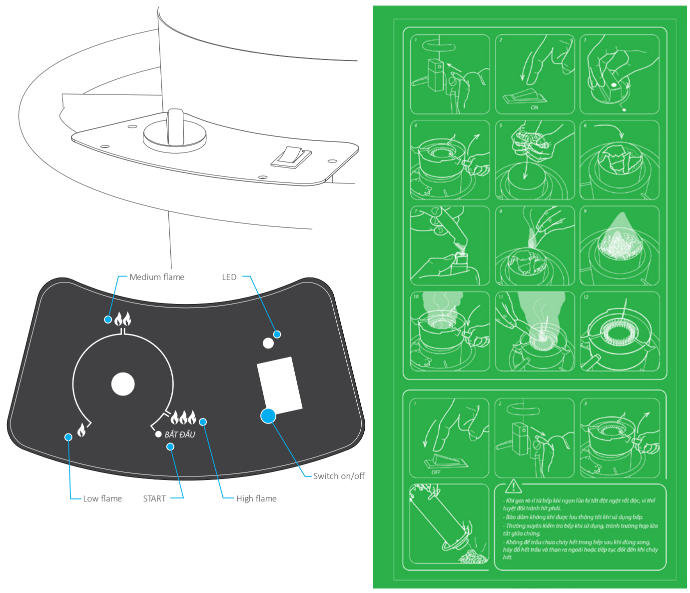


Image B.3.5: Control panel and user instructions

APPENDIX B.4: DEVELOPMENT STORY, CCS GASIFIER STOVES

In the past six years CCS has developed many different prototypes for both wood pellet and rice husk gasifiers. In this paragraph an overview of these stove prototypes are given with a short analysis on their characteristics.

2010 model

The first gasifiers that CCS made, were rice husk gasifiers. These models, in figure *B.4.1*, date back to 2010. These versions did not provide any thermal insulation, so the outer surface became very hot and was dangerous when touched by accident. They are both based on a TLUD design but differ in the way of unloading the biochar. One has to be tilted completely over, whereas with the other one the biochar can be disposed from a drawer at the bottom.

After this version Rob and Joan worked on the project and took a big leap in the development of rice husk gasification compared to the old versions.

Shift to wood pellets

After Joan his gasifier project, focus shifted towards wood pellet gasifiers. According to CCS employee Hai, there were four main reasons for doing this:

1. Wood pellets contain a much higher calorific value per cubic meter. This means that the gasifier can be developed smaller, as it only needs a fraction of the volume of rice husk gasifiers.
2. Rice husk is not available throughout the year. It is also not profitable to transport towards other areas because of their low bulk density. Besides this rice husk can be turned into pellets.
3. Pellets are already being produced in mass quantities for industrial applications such as energy plants in Vietnam. Though they do not have an established distribution network for the consumer market yet, it can be implemented.
4. When the syngas that is being produced by rice husk is not burned it is more toxic and dangerous for users compared to wood pellets.

2013 model

The first wood pellet gasifier of CCS had natural draft primary air and natural draft secondary air. The design of the burner was much like the one Joan made but did not produce a strong flame with efficient combustion. Still this stove provides a cleaner combustion compared to open fires.

Image B.4.1: 2010 and 2011 rice husk gasifier prototypes

Image B.4.2: 2012 rice husk gasifier based on Belonio's design

Image B.4.3: 2013 natural draft pellet gasifier

2014 model

The improved version from 2014 changed three main components compared to the preceding version. *Firstly,* a fan is added to have forced primary air. The power of the flame could now be controlled and the efficiency increased. *Second*, the dimensions changed. The diameter of the reactor decreased, having a smaller reactor creates less syngas but this can be compensated by having a higher quality syngas with the fan. The amount of secondary air holes was also reduced. *Thirdly,* the burner changed. The flame is now concentrated in the center so less of the heat escapes along the side when smaller pots are being used. Another difference compared to the old burner is, the previous burner heated the gasifier as the flames touched the overlapping metal. This version has been thoroughly tested by an institute which concluded that an efficiency of 37% was reached. More details on this report can be found in chapter 4.3.

2015 model

This version from 2015 changed two main components. The fan was now used for both, forced primary and secondary air. There is no valve to regulate the different air streams but the surface area of both air inlets are almost evenly divided. The burner was changed to have a more concentrated flame. The secondary air was mixed inside through channels which makes this burner a more complex build compared to previous versions but improves the mixing of the gas.

2015 model improved

Because of the lack of control around the amount of primary and secondary air flow a new version was made for testing purposes. In this version two fans could be controlled independently. This resulted in a very powerful flame and showed just how important a good airflow ratio is for the performance. The PVC tubing was added later to use just one centrifugal fan instead of two axial fans and control the air flow with valves.

Shift towards centrifugal fans

Fans that have been used until now were *axial fans*. Axial fans create airflow with a high flow rate, meaning they create a large volume of airflow. However, the airflows they create are of low pressure. They require a low power input for operation.

The airflow created by *centrifugal fans* is directed through a system of ducts or tubes. This helps create

Image B.4.4: 2014 version forced primary air, draft secondary air

Image B.4.5: 2015 model forced primary and secondary air

Image B.4.6: improved 2015 model with separate control for the secondary air a higher pressure airflow than axial fans. Despite a lower flow rate (compared to same sized axial fans), centrifugal fans create a steadier flow of air than axial fans. Centrifugal fans also require a higher power input.

2015 model (most recent)

The most recent version of the gasifier was built in the first week of my arrival in Vietnam. It was reasoned that the fuel capacity of the previous version was not enough to perform all the cooking tasks. Therefore, to make a better fit with the user needs, a new version was built with a larger reactor. Two simple valves were added to control the primary and secondary air flow ratios. This stove is analyzed to more extent in appendix C.3. Image *B.4.8* shows the air tube with divided paths for the primary and secondary air with a valve for regulating the primary/ secondary air ratio.

Image B.4.7: 2015 model gasifier with improved burner and airflow control

Conclusion

CCS has gained a lot of experience with the development of gasifier stoves. Their progress is not very well documented, but the amount of prototypes clearly shows the time and effort that has been put into improving the stoves. This does make it difficult for outsiders to catch up with what has already been done. Fortunately, all the prototypes are still present in the office of CCS and were easily assessed. Until now all of the prototypes are made from high quality steel which could be decreased in thickness and quality to decrease the price.

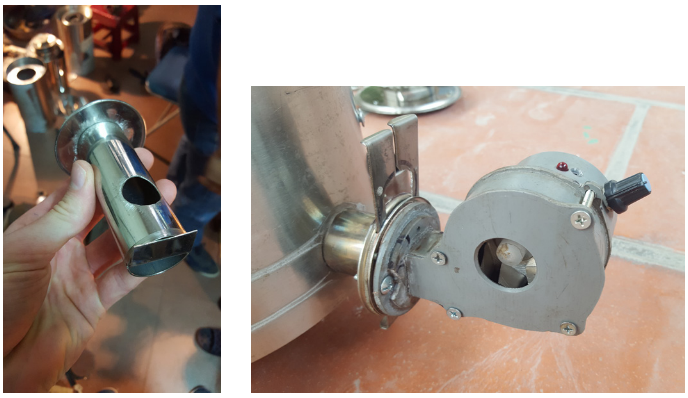
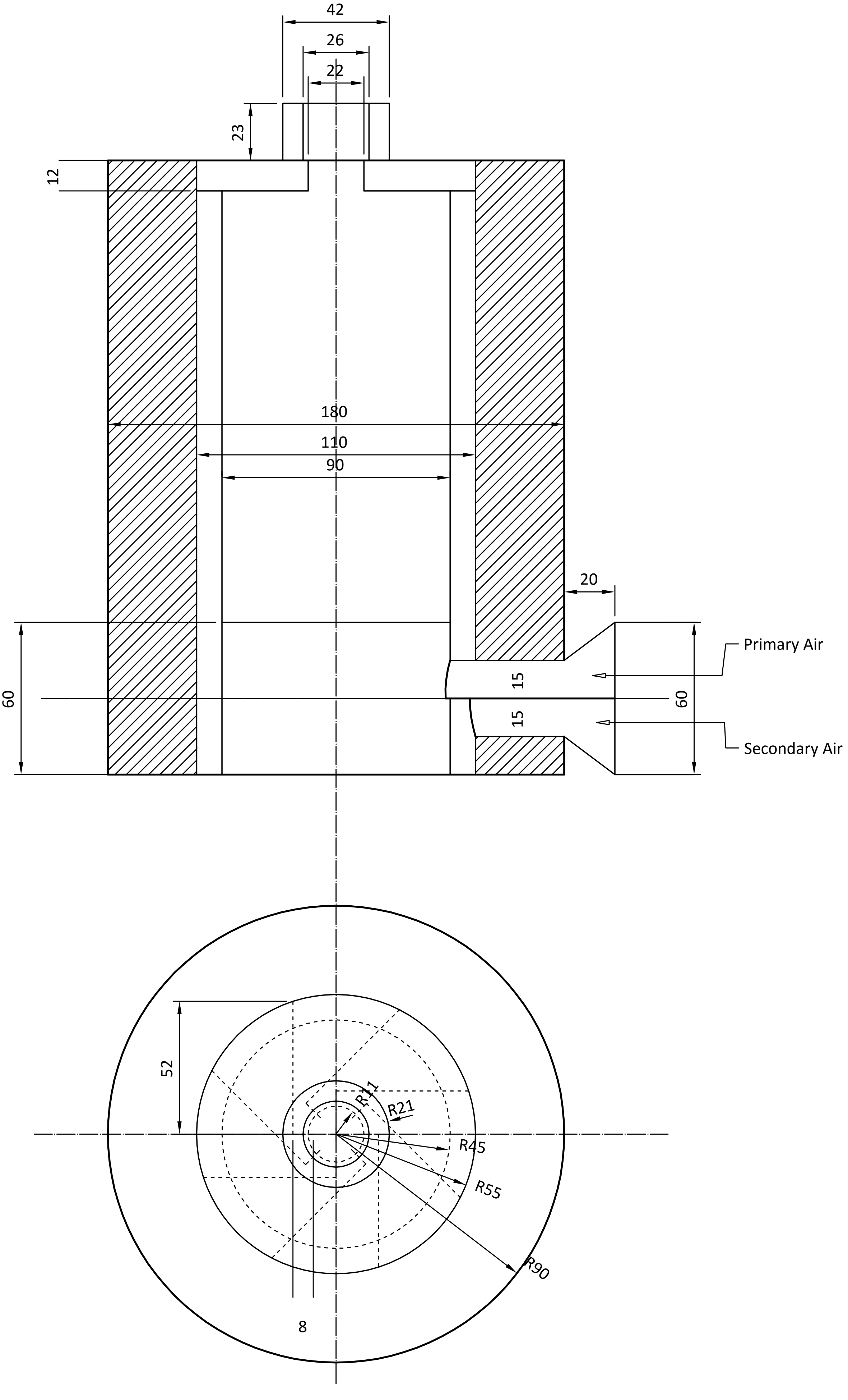


Image B.4.8: Close-up pictures of the air tube, valve and centrifugal fan

Image B.4.9: Picture of the gasifiers from CCS giving as presented during their workshop

APPENDIX C: ANALYSIS


42
26
22
23
12
180
110
90
20
Primary Air
15
15
60
60
Secondary Air
52
R11
R21
R45
R55
R90
8

APPENDIX C.2: ASSIGNMENT MODEL ANALYSIS

Before coming to Vietnam an attempt was made to get a better understanding of the subject and current situation of CCS. This appeared to be a difficult phase as documentation was limited and communication did not always progress fluently. Several Skype meetings were planned to make a clear overview of the different tasks that had to be done and were set on making a gasifier that is ready for mass production.

Starting with modeling the gasifier in SolidWorks from the image below and a technical drawing of appendix C.1 will provide insights in the different parts that are being used in the gasifier to get familiar with the concept.

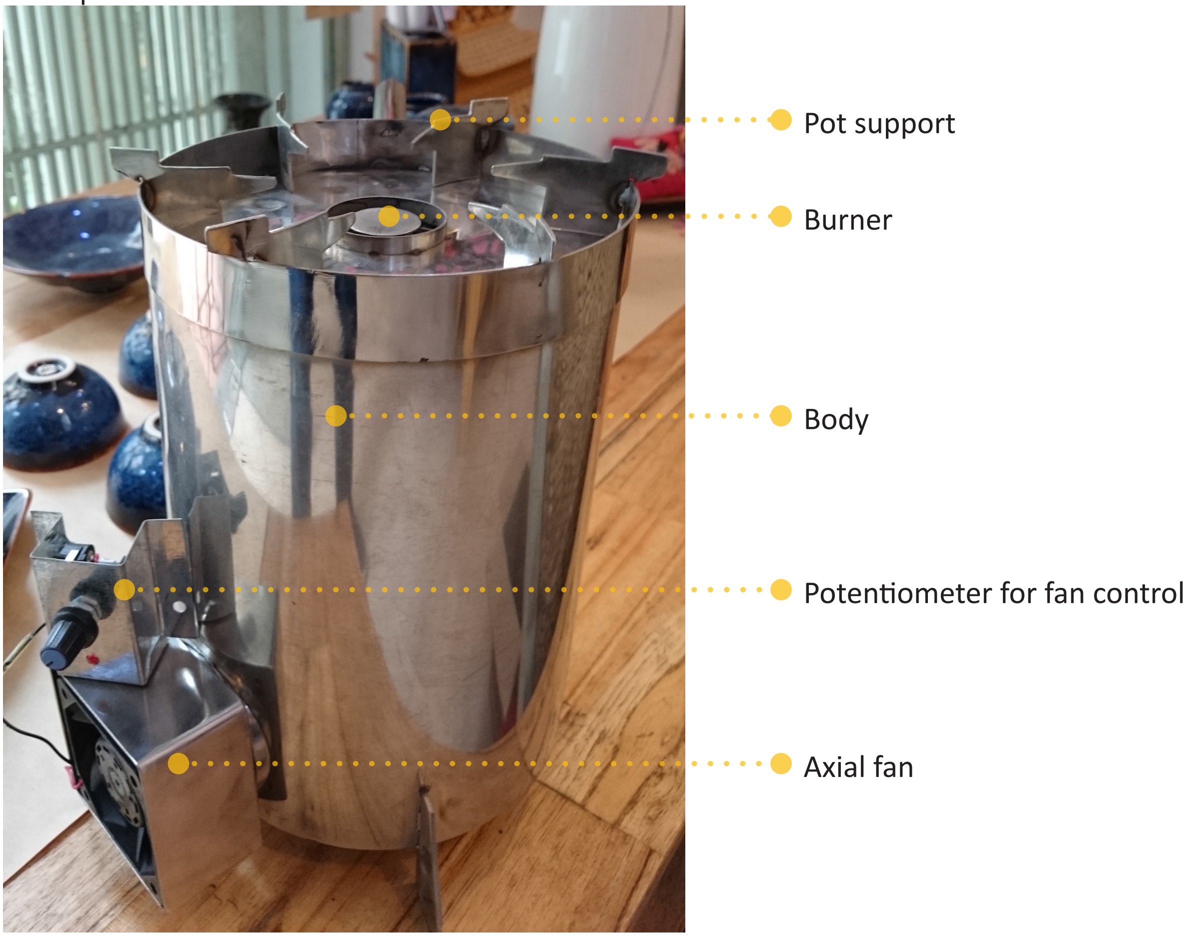


Image C.2.1: Gasifier as given by the assignment

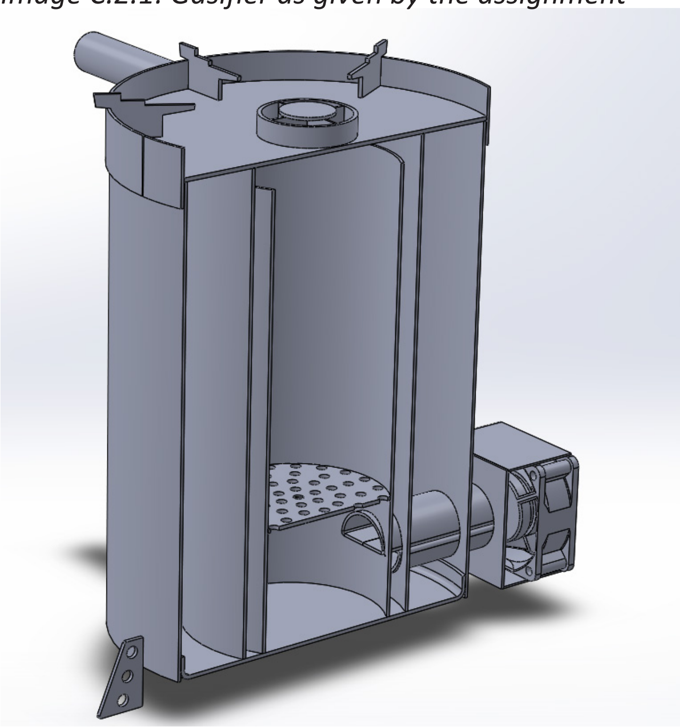


Image C.2.2: SolidWorks model of gasifier stove

SolidWorks model
Building a SolidWorks model will provide the following insights:

- The different parts that are used
- Dimensions of the parts
- How the prototype is build-up
- Support in communication
- Calculating the weight of the components for price estimation
- Making technical drawings to get quotations and advice from manufacturing partners
- Renders for presentations

APPENDIX C.3: PROTOTYPE ANALYSIS

Burner

The burner is one of the most critical components for the performance of the stove. The main functions are:

- Mixing the primary and secondary air flow.
- Creating a stable flame by regulating the gas pressure.
- Concentrating the flame to a central point.
- Insulation of the primary and secondary air, from unwanted tertiary air.
- Compatibility with cooking equipment.


Image C.3.1: Close up of the burner mixer

The latest burner design of the CCS gasifier is shown in the images on the right. This design consists of two modules. The first module is placed on top of the reactor to concentrate the primary air and provide guidance for the secondary air. The second module is to stabilize the flame and seal off the primary and secondary air. The larger disk around the top burner is to prevent heat is lost when flames are reflected from the bottom of a pot.


Image C.3.2: Close up of the burner top

Production

This design has many different parts and is quite labor intensive to manufacture. All the components from the burner can be made from sheet metal. The top part of the burner sown in image C.3.2 can be made by simple sheet metal processes like deep drawing and punching. It would require for this design to produce at least 4 different molds.

The other part is produced with metal shearing, metal bending, stamping and welding. The bottom can be stamped from sheet metal.

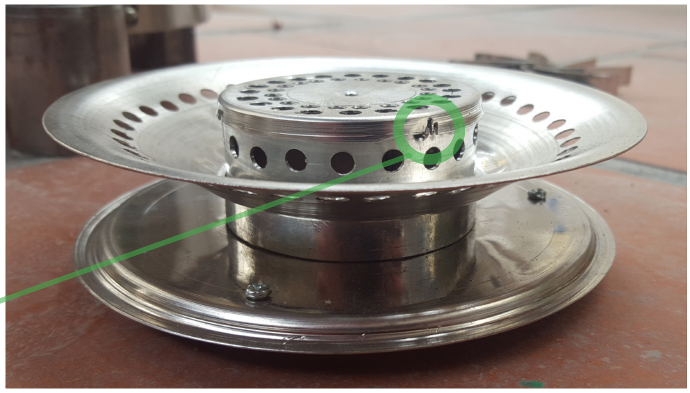


Image C.3.3: Bended lips for assembling the burner

Assembly

For the air mixer, a simple container can be made to place the eight wings in the right position before point welding them to the bottom plate.

The assembly of the top of the burner is done with screws and the bending of lips to pinch two parts together.

Conclusion

Therefore, one of the design goals is set to design a burners that can be produced using mass production techniques.

Pot support

The most important function of the pot support is to give support to an optimal number of cooking equipment such as pots and pans. Besides this the pot support can also have great influence on the efficiency of the gasifier. When pots are placed too high from the flame a lot of energy is lost in heating the air between the burner and the bottom of the pot. When the pot is too close to the burner, flames might escape from the side where the energy is also lost to the environment. In extreme cases the pot might obstruct the flow of gas completely which could then kill the flame.

For stoves with forced secondary air the gasifier is less dependent from tertiary oxygen from the environment. The additional oxygen is already provided by the secondary air supply.

Different pot supports have been used overtime like the one in Joan's gasifier, three simple pieces are cut from a sheet metal plate (see figure C.3.4). This design also accounts for smaller pots to be closer to the flame while big pot has a larger distance. In some of the prototypes the pieces were bent which is something that should be improved.

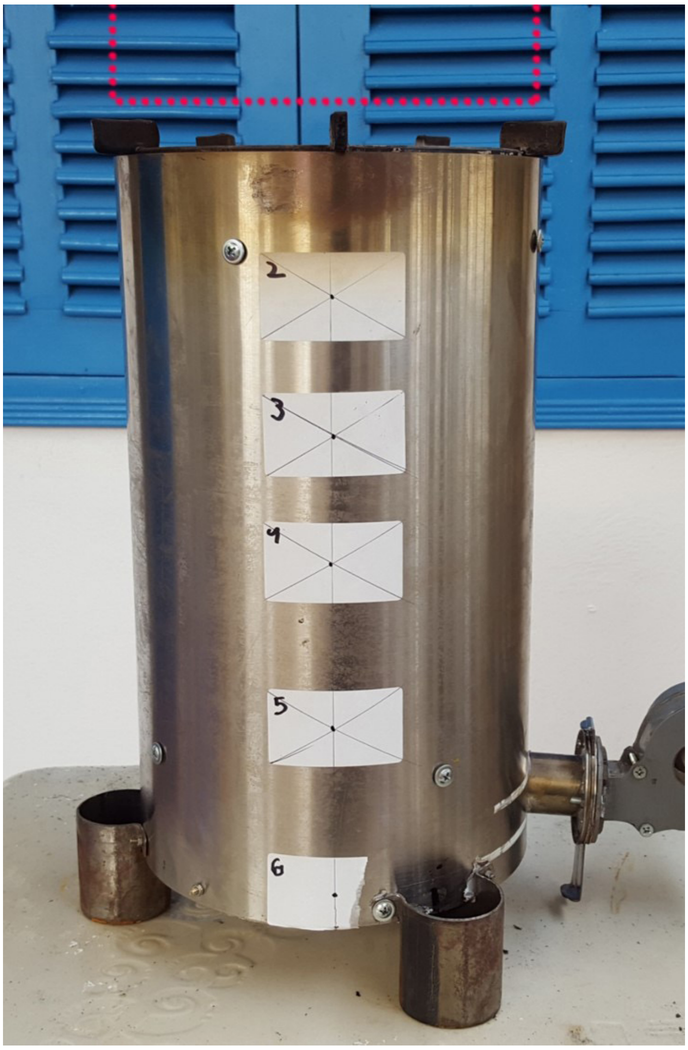


Image C.3.4: Side view of the gasifier and pot support ring


Image C.3.5: Close up of the pot support ring


Image C.3.6: Old CCS concept with simple pot support

Dimensions

Families in rural areas in Vietnam use aluminum pots and pans that do not have standard dimensions. However, from observation the most common pots seen are small pots/teapots of 14-16 mm diameter, mid-size pots of 20-22 mm diameter and big pots of 26-30 mm diameter.

Production

There are some options here for providing pot support to the gasifier. The currently used pot support is a part from a gas stove but can be purchased from a manufacturer as a buy in part.

The other possibility is to produce it yourself, this can either be done based on the design of Joan and could be produced using a stamp and sheet metal. A new design can be developed as well where it can add to the aesthetics or additional features can be added.

Assembly

The buy in part requires no assembly and provides good stability. The other support is welded on top, here alignment features should be added to evenly distribute them around and to place them straight.

Reactor

The reactor of this gasifier is a simple stainless steel tube with a metal grade at the bottom. Because of the modular design approach it can be taken out from the gasifier easily. This has two major advantages, the first is that it can easily be replaced. The temperatures inside the reactor can reach up to 1300 °C, this means that the material is prone to big temperature differences which deteriorates the material over time. The second advantage of taking the reactor out when emptying the biochar is that the reactor can be inspected for visual defects. When for example there is a hole somewhere it might damage the gasifier when it is not fixed on time.

The grade at the bottom should keep the pellets (and char at the end of the process) from falling down and has to let primary air through. It should be resistant to high temperatures and resist the weight of the pellets. At first sight it looks like it might not be the strongest option but future test should determine if this is good enough.

Dimensions

The diameter of the reactor determines the amount of gas produced, and the height of the reactor determines the length of time that this gas is produced. These dimensions are therefore dependent on the requirements set by the user. From the previous analysis it was determined that the user should at least have 45 minutes of cooking time. Testing should determine if the current dimensions are adequate:

- The height of the reactor is 24,4 cm
- The inner diameter is 16,6 cm
- The thickness is 1,5 mm
- The weight of the empty reactor is 863 gram

Production

For the production of the reactor it is a good option to go for a standardized size tube like it is done in the current version. The only production step for this piece is to cut the standardized tube with the right length. Advantage of this is that it can be very cheap and there is no need for investment in special tooling.

For the production of the grade a thin wired metal fabric is used. Another option is to buy pre-perforated sheet metal plates.

Assembly

A thin metal ring acts as a clamp to hold the grade in its place, this is then bolted onto the cylinder.

Image C.3.7: Weight of the empty stainless steel reactor tube

Image C.3.8: Emptying the biochar from the reactor

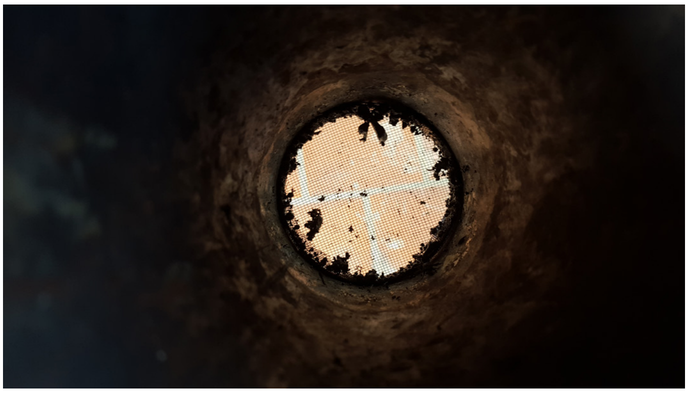


Image C.3.9: Slug left behind after the gasification operation

Body

The body of the gasifier is the outer shell which is custom build from a stainless steel plate. The function of the body is to insulate the reactor and provide attachment points for the other parts. It should also be cool enough for users to not get directly burned when they touch it accidentally. Besides this main functionality in this design, the body also acts as a windshield for the flame and to provide additional height for the pot support.

Secondary functionality that the body could provide is to increase the aesthetics of the device. A layer of paint or sticker can be used to adjust the product to specific user demands, making it fit better within the target market.

The current plate is quite thick, 1 mm, which could be decreased to decrease the price. Other materials can also be investigated which might provide a cheaper option.

Image C.3.10: Body of the CCS gasifier prototype 2015

Production

A sheet metal plate is processed in a three bend rolling machine (see image C.3.11). The dimensions of the sheet determine the diameter and height and should be cut in advance. Holes are drilled afterwards, but this could be done in advance for higher production volumes. After the sheet is bent the two sides are welded together.

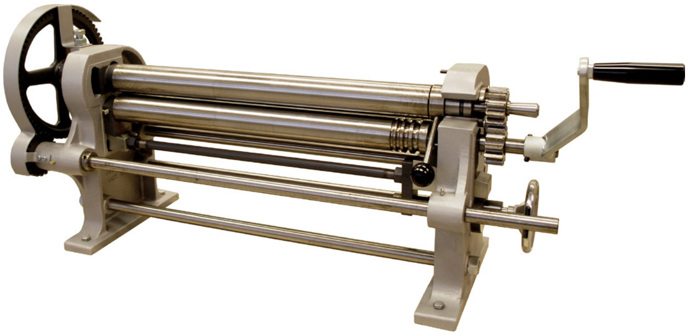


Image C.3.11: Three bend roll machine for sheet metal forming

Insulation

The gasifier is insulated with glass wool. This is sold in big rolls of 12 kg and cost around 300 000 VND which is around 13.4 USD. The function of the insulation is to prevent heat from being transferred from the reactor to the environment. It should also keep the body cool when operating the stove. It has to be tested if this provides the best way of insulation for the stove.

Image C.3.12: Glass wool insulation

Fan

The fan is an important part of the gasifier it provides air for a cleaner combustion. Besides this the speed of the fan which controls the intensity of the flame can be controlled by a potentiometer. These are important characteristics as it will allow users to adjust the stove to their cooking needs. If water needs to be boiled fast, the fan can be set to maximum speed which adds oxygen to the combustion reaction using more fuel. If a pot just needs to simmer for a while the fan can be turned down to a lower speed which results in a lower fuel consumption.

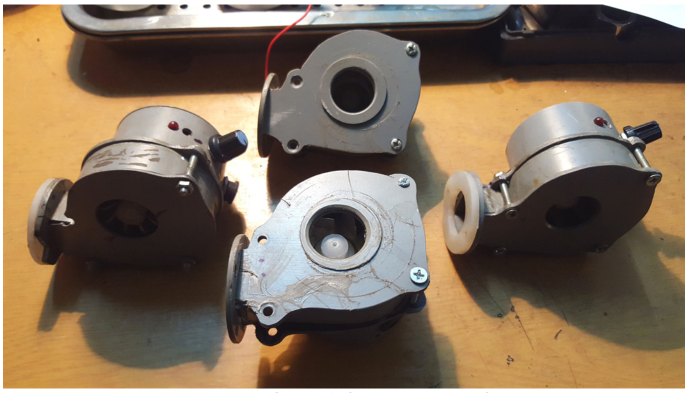


Image C.3.13: Centrifugal fans manufactured by CCS

Production

Instead of using a standardized fan CCS produced one themselves. The body is all made from PVC tubing, a special stamp has been made to cut the different parts from a PVC plate. The fan blades are folded around a mold (see image on the right).

Image C.3.14: Molds for centrifugal fan blades.

Conclusion

It should be investigated if this part can be bought from suppliers when moving to mass production. It is also interesting to explore why they have decided to make the fans themselves. The fan is not integrated in the body which could make it vulnerable for any accidental damages.

Air control valve

The air control valve is made from two simple plates (see image C.3.16). The primary function is to enable the user to adjust the ratio of the primary and secondary air. When one of the slides is pushed down, more of the channel will be blocked allowing less air to go through that channel. It has to be investigated if this control is clear for users or if a fixed air ratio can be used. The latter would decrease the amount of parts which saves assembly times and production costs. It would also be easier for users as the only functional control is the speed of the fan.

Image C.3.15: Close up image of the centrifugal fan attached to the gasifier with control valves

The air tube is divided by a small plate through the tube. The primary air flows through the end of the tube whereas the secondary air flows at the hole on the side. It has to be investigated if the air is divided equally in this configuration.

Image C.3.16: Air flow division tube for primary and secondary air

Production

Cutting a standard tube to the correct length, bending a sheet metal strip for the valves and plate for dividing the two air flows.

Feet

The feet of the gasifier should provide stability even when big pots are placed on top. Having three support points will ensure that the gasifier is stable even when the ground is not completely level. At the end of the gasification process the bottom plate will get very hot due to radiation of the char. If the gasifier would be used on a table it is important that the bottom plate does not make direct contact with the table or it could damage the surface.

The current design is a quick solution, it should be improved on aesthetics, producibility and price.

Production

The feet in this model are made from a standard tube with a cut from the side. The sides of the cut are bent outwards so it can be bolted onto the gasifier.

Air flow simulation

Using SolidWorks flow simulation, the airflow that is created by the fan is investigated. The goal of this study is to get a better understanding on how the air behaves inside regarding the flow trajectories and speed.

Assumption

Also this simulation did not take into account the effect of fuel on the air flow.

Setup

There are two boundary conditions, one at the top which simulates the environmental pressure and one at the inlet of the fan. A standardized centrifugal fan has been selected from the library.

Conclusion

Looking at the flow trajectory it can be seen that the secondary airflow creates a vortex at the bottom and around the reactor. It is intended with this design that the airflow will be spiraling around the reactor after which the blades of the burner catch this spiral and mix it with the primary air. It has to be investigated in practice if this effect is sufficient for mixing the two air flows.

The speed of the primary air increases when it is forced through the burner at the top. This could benefit the efficiency as the velocity is used to mix the two air flows. If the speed is too high, it might result in blowing off the flame from the burner.

Image C.3.17: Feet of the CCS prototype

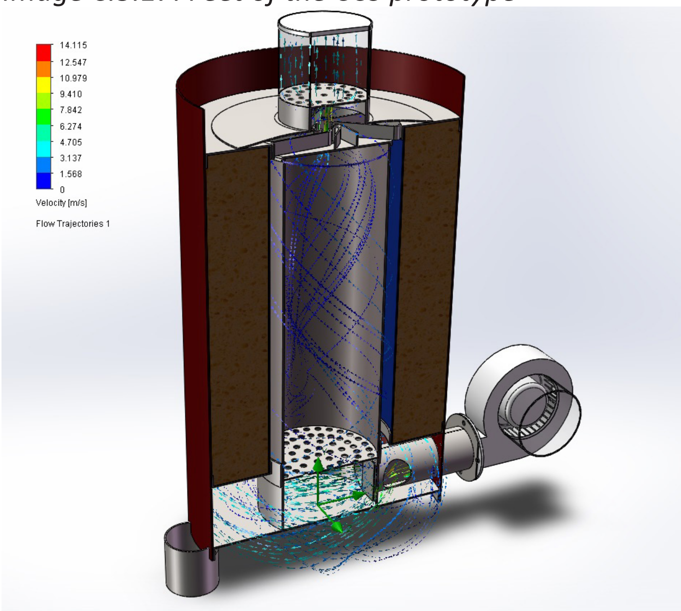


Image C.3.18: Flow simulation within the gasifier

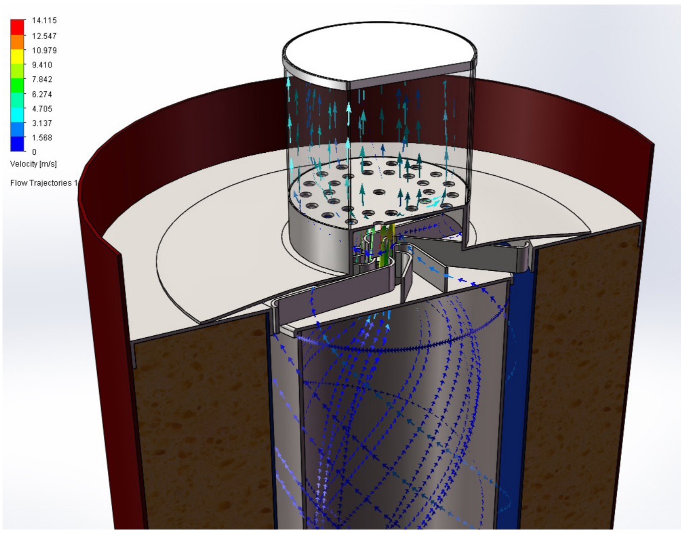


Image C.3.19: Flow simulation at the top

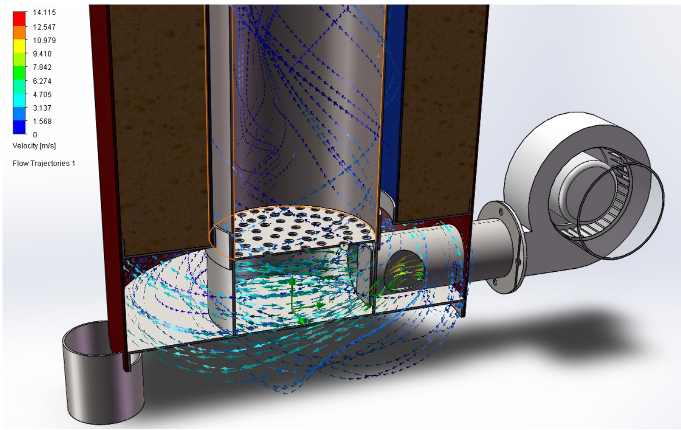


Image C.3.20: Flow simulation at the bottom

APPENDIX C.4: SITUATION ANALYSIS

Positives

- CCS has fast and easy access to prototype and test these ideas in their workshop.
- CCS gained a lot of experience with micro gasification cookstoves in the past 5 years.
- Performance of the current version of the CCS gasifier stove is good (close to tier 4) compared to other stoves in the market.
- Gasifier cookstoves can have potential savings in fuel cost for consumers.
- CCS has a lot of contacts with (potential) partners for future development. These partners range from government officials, potential investors to manufacturers.
- CCS employees have knowledge on the gasification process. Understanding the chemical combustion reactions help with making design choices.
- CCS its focus is not only on the consumer market, industrial applications of a gasifier are also being developed.
- CCS has technical support by students with technical background and industry experts.
- CCS has knowledge on the consumer market in Vietnam.

Negatives

- CCS just started on its own and has to make its own revenue instead of relying on funding. Therefore, financial recourses are limited.
- CCS has a lack of proper documentation of test results and designs.
- CCS has its focus on a lot of activities at the same time, this sometimes results in ineffective working.
- There are no established sales channels for the gasifier.
- There are no established sales channels for the pelletized biomass fuel needed for the gasifier.
- All the gasifiers that have been developed got stuck in the prototyping phase.
- There is a loss in focus on the user needs for different markets. They have not been written down and are not clearly communicated in the designs.
- CCS does not own the equipment to do accurate tests on efficiency and emissions themselves, but does have the connections with SNV to get a certified test report.

Chances

- Improved cookstoves have gained a lot of (recent) attention globally in news reports and television and hot topics are potentially more interesting to possible investors. See appendix B.1 for a newspaper article on the subject.
- Multiple countries plan or have started programs for the distribution of advanced cookstoves.
- Pellitizer machines of biomass fuel are not expensive and are sold for under 3000 USD.
- The market is big, there are a lot of people having problems caused by their traditional way of cooking.
- People are becoming more aware of the issues caused by their traditional ways of cooking, especially regarding their health.
- There is a growing scientific recognition that improved household fuel technologies can support climate change migration and deforestation.
- Stoves might qualify for carbon financing, which means that carbon credit gained by the usage of a clean cookstoves can be sold to companies or government.

Dangers

- The price of biomass fuel cannot be controlled and might increase when demand increases. This would mean that cooking on gasification could loose one of its most important advantages.
- Pellet gasifiers are dependent on the distribution of the pelletized fuels.
- People become more aware of the health issues caused by their traditional way of cooking but do not want to change when the alternative is more expensive.
- Moving to a different cooking technique requires a change in cooking behavior, which is not something people tend to do easily.
- Batch operation stoves might not fulfill the user needs.
- For some people in Vietnam fuel is currently freely available, when they gather it from the forest and have therefore no financial benefits when switching to a gasifier.
- There is great deal of competition globally, big companies like Philips, BP and other start-ups try to profit in this market.
- Some people have had a bad experience with poor functioning gasifiers and will therefore be reluctant to invest in a new one.
- Not every stove manufacturer uses the same methodology for testing the stove its

performance. This makes it difficult to compare the stove reliably.

- Stove tests that are executed in labs may not have the same results as when they are used by consumers.
- Consumers fail to see the long term economic benefits of using a gasifier cookstove especially when the initial investment is relatively high.
- A lot of money is being invested in advanced cookstoves by countries and companies. However, it appears to be rather difficult for small entrepreneurs to get actual financing for their stove projects.
- When used improperly, a gasifier can potentially be dangerous for consumers. For example, when the flame blows off the gasifier will keep on generating toxic gas spreading into in the room.

APPENDIX D: STOVE RESEARCH

APPENDIX D.1: FAN FROM MASS PRODUCTION PARTNER

The performance of the fan that is produced by CCS is good enough for most cooking tasks. It might even be too powerful for grilling and frying (see user research in chapter 3.5) when the fan speed is at its maximum, but this can easily be controlled by the potentiometer. For this reason, a fan with similar performance should be purchased from retailers.

Different Chinese fan suppliers have been approach through Alibaba, an Internet marketplace for production companies. 6 different types of fans have been ordered to see which one will meet the requirements of the gasifier the best. Also a quotation on the fans has been submitted for when the gasifier would go in mass production (100 000 pieces) and large quantities are ordered. Respondents said they are able to offer fans between $1 and $1,5 dollar depending on the type.
Advantages of working with a supplier for the fan are clear. They can make the fan according to specific requirements and offer a warranty on their product.

The following samples were ordered to have a wide range of units for testing:

- Blower fan 57.5mm*56.5mm*28mm-12V-4500RPM-ball bearing- HS8414599050 2 $3 $6
- Blower fan 75mm*74mm*29.5mm-12V-3500RPM-ball bearing- HS8414599050 2 $3 $6
- Blower fan 97mm*95*33mm-12V-3500RPM-ball bearing- HS8414599050 2 $3.6 $7.2
- Blower fan 97mm*95*33mm-12V--5000RPMball bearing-5000RPM HS8414599050 2 $3.6 $7.2
- Blower fan 120mm*120mm*32mm-12V-2400R-PM-ball bearing- HS8414599050 2 $4.7 $9.4
- Blower fan 120mm*120mm*32mm-12V-3300-RPM-ball bearing- HS8414599050 2 $4.7 $9.4

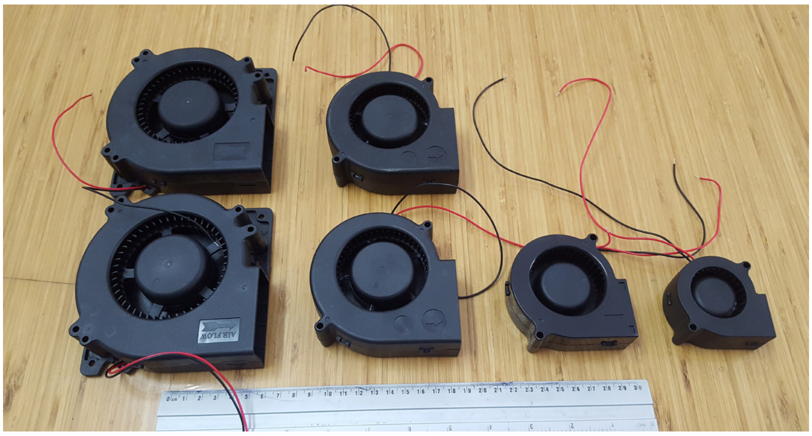


Image D.1.1: Centrifugal blower fan samples from Chinese manufacturing supplier

Size (mm)	Model	Rated Voltage (VDC)	Current Amp (A)	Speed (rpm)	Air flow (CFM)	Static Presser (mm H2O)	Noise lev-el (dB-A)	Weight (g)
57.5	XJ12B6028H	12	0,30	4500	12,35	10.67	42	47.00
75	XJ12B7530H	12	0,30	3500	12,35	11,00	44	77
75		12	0.45	4500	22			77
95	XYJ12S9733H	12	0,46	3500	26,30	23,70	52	168,00
95		12		5000				168,00
120	XJ12B12032H	12	0,68	2400	37,68	27,22	51	212.00
120		12		3300	48			212.00

Table D.1.1: Sample that have been ordered for CCS

APPENDIX D.2: 75 MM BLOWER

The fan that matches the performance of the one that CCS made is the 75 mm blower. The measurements and performance curve are given by the manufacturer in image D.1.3 and D.1.4 below.

Image D.1.2: Blower fans from Xinyujie

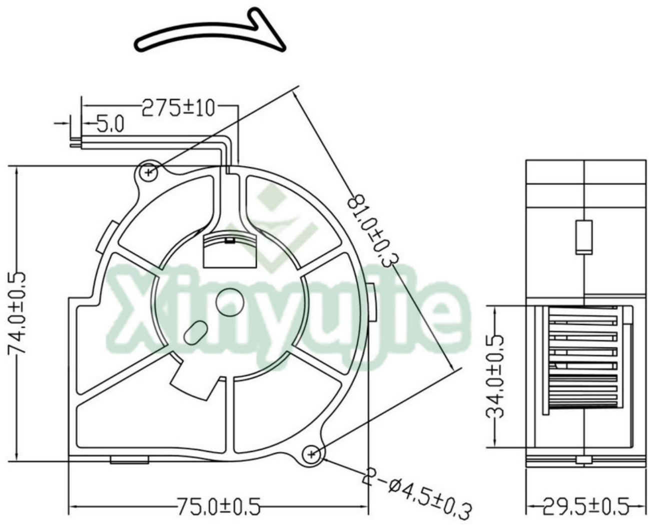


Image D.1.3: Dimensions of the fan

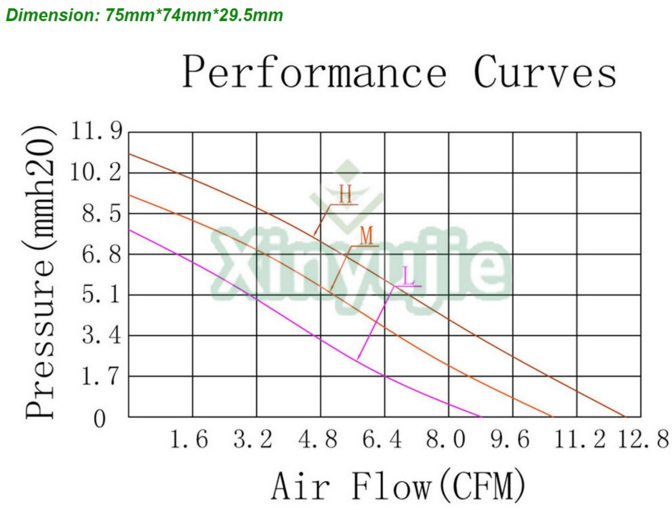


Image D.1.4: Performance curve

APPENDIX D.3: USER TESTING SHEET

Guidelines for user testing

- Interfere as little as possible during the test.
- Answer their questions when they have a doubt.
- Do not tell them if they are doing it right or not. Let them make mistakes.
- Take notes and pictures of the test.
- Write down carefully what is done and especially what surprises you the most.

	Answers	Test 1	Test 2	Test 3
Familiar with gasifier stoves	Yes/ no			
First time users	Yes/ no			
Current cooking meth-od	-Gas stove -Beehive coal stove -Wood stove (open fire) -Electric stove -Rice cooker -Charcoal stove			
Fuel used	-Rice husk -Wood pellets -Wood -Straw			
Quantity	(Grams)			
Water amount	(Liters)			
Initial temperature	(Environmental temp)			
Duration	(Time to boil) (Total operation time)			
Fan speed	Low/ med/ high			
Flame characteristic	-Yellow -Orange -Blue -Invisible			
Posture user	-Standing -Crouched -Sitting			
Number of times ad-justing the fan speed	# number			
Number of times ad-justing the valves	# number			
Observation notes				

Proposed questions
Ask some questions in the end to obtain extra information or confirm the observations.

What did you like the most? Least?	
What other biomass would you like to use?	
How easy is it to get wood pellets in your village?	
Where will you use the gasifier (location)?	
For what cooking tasks will you use the gasifier?	
Is the high temperature of the surface body a problem?	
How long would you like to cook?	
Do you understand how to use the air valves?	
How much do you want to pay for the gasifier?	
Would you buy the gasifier if it is sold for under $20?	
What is the size of the cooking pots you use?	

APPENDIX E: GASIFICATION

APPENDIX E.1: EMISSION TIER SCALE

The emission of the stove is determined with a Water Boiling test which is described in the next chapter. The table below shows the emission values that need to be reached for each scale.

Emissions CO Sub-tiers		
	High Power CO (g/MJd)*	**Low Power CO (g/min/L)**
Tier 0	>16	>0.20
Tier 1	≤16	≤0.20
Tier 2	≤11	≤0.13
Tier 3	≤9	≤0.10
Tier 4	≤8	≤0.09
* g/MJd is grams per megajoule delivered to the pot		

Emissions PM2.5 Sub-tiers		
	High Power CO (g/MJd)**	**Low Power CO (g/min/L)**
Tier 0	>979	>8
Tier 1	≤979	≤8
Tier 2	≤386	≤4
Tier 3	≤168	≤2
Tier 4	≤41	≤1
** mg/MJd is milligrams per megajoule delivered to the pot		

Indoor emissions Sub-tiers		
	Indoor Emissions CO (g/min)	**Indoor Emissions PM (mg/min)**
Tier 0	>0.97	>40
Tier 1	≤0.97	≤40
Tier 2	≤0.62	≤17
Tier 3	≤0.49	≤8
Tier 4	≤0.42	≤2

Efficiency/ fuel use Sub-tiers		
	High Power Thermal Efficiency (%)	**Low Power Specific Consumption (MJ/min/L)**
Tier 0	<15	>0.050
Tier 1	>15	<0.050
Tier 2	>25	<0.039
Tier 3	>35	<0.028
Tier 4	>45	<0.017

Safety	
	Scale of 0 to 100***
Tier 0	<45
Tier 1	≥45
Tier 2	≥75
Tier 3	≥88
Tier 4	≥95
*** Point from ten weighted safety parameters.	

APPENDIX E.2: SAFETY TIER SCALE

Due to increased popularity of cookstoves in the market, low quality stoves with little concern for safety have increased domestic injuries among users. Therefore based on the US standards governing design safety of indoor and outdoor gas cooking appliances as their model [ANSI, 2000 and ANSI, 1993], simplified analytical guidelines to enable safety assessment were set up. A four-point scale from "Poor" to "Best" was used to indicate levels of safety and encourage design improvements. Ten tests make up the safety evaluation guidelines:

1. Sharp edges/Points	Exterior surfaces of a cookstove should not catch or tear any article of clothing or cut hands during normal use
2. Cookstove Tipping	Cookstoves should come back to rest upright after being slightly tipped from their original position
3. Containment	Flaming embers should rarely fall from the cookstove when it is overturned
4. Expulsion of Embers	Embers should have little chance of being expelled from the cookstove
5. Obstructions near Cooking	The area surrounding the cooking area should be flat
6. Surface Temperature	Burns should not occur if the cookstove surface is touched for a short duration
7. Heat Transmission to Surroundings	Cookstoves should not cause dangerously elevated temperatures on surrounding surfaces in the environment
8. Cookstove handle temperature	Cookstove handle temperatures should not reach a level where use can cause harm either directly or indirectly
9. Flames surrounding cookpot	Flames touching the cookpot should be concealed and not able to come into contact with hands or clothing
10. Flames Exiting the Fuel Chamber	Flames should not protrude from the fuel loading area

Table E.2.1: Safety tier criteria

Certified stoves must also include complete installation manuals with detailed operating instructions, fuel specifications, recommendations to use qualified installers, and labels presenting stove performance figures.

SOURCE: A Summary Review of Global Standards and Test Protocols Relating to Product Quality Standard Development for Household Biomass Cookstoves

APPENDIX F: EXPLORATORY STUDY

APPENDIX F.1: VIETNAM COOKING TRADITIONS

The North is known for their mild taste and a preference for noodles. The Centre of Vietnam for its spiciness and the South, for its sweetness and preference for rice. The different historical shifts have influenced the Vietnamese cuisine a lot and economic conditions forced to maximize the use of ingredients. It can also be noted that everything is used, nothing is gone to waste.

On the streets of any city or town, there are street vendors that sell fresh vegetables, meat and fruits. There are also local markets where a more variety of food and ingredients can be purchased. However, there is an increasing trend among young people in the cities to prefer preserved or packaged foods in the supermarkets

Northern Vietnam

The northern Vietnamese food clearly shows the centuries of Chinese occupation. Implementing noodle dishes as can be seen in image F.1.1 on the right.

Bun Cha

This popular dish is served by many street vendors in and around Hanoi. Ingredients are noodles with fresh vegetables salad and barbecued pork.

- Cooking techniques used for making this dish are the beehive coal stove to keep a large pot warm for preparing and heating up the noodles
- A small BBQ to roast the pork
- A small hot pot to keep the soup warm (or it can also be kept in a thermos. When it gets cold it is usually quickly heated on a gas stove

Interesting to notice is that not all street vendors prepare, or have their own ingredients in stock. Fresh noodles are delivered to the food stalls and only heated for a few seconds to serve them warm. Just like the fuel the owner calls their fixed supplier when they run out, then they are either delivered by bicycle or motorcycle.

Image F.1.1: Vietnamese dish, Bun Cha sold in Hanoi

Image F.1.2: Pork being BBQ-ed on a street in Hanoi

Image F.1.3: Different pots and stoves of a restaurant

Pho Bo

Translated means beef noodle soup, often sold by street vendors and one of the typical dishes that can be found on the streets in the north. Southern Vietnamese eat it for breakfast and occasionally lunch, whereas those from northern Vietnam consume it at any time of day. Street vendors that serve this dish use fresh vegetable and noodles. Pots are also heated on beehive coal stoves

Image F.1.4: Typical Vietnamese dish Pho Bo

Bánh cuốn

Bánh cuốn is made from a thin, wide sheet of steamed fermented rice batter filled with a mixture of cooked seasoned ground pork, minced wood ear mushroom, and minced shallots. Sides for this dish usually consist of chả lụa (Vietnamese pork sausage). This dish can be prepared with only one stove either a gas or beehive coal stove.

Image F.1.5: A women preparing Bánh cuốn on the streets of Hanoi

chả giò (Nem)

Nem or spring rolls are one of the most widely known snacks of Vietnam. There are a variety of different rice paper rolls containing meat, or just vegetables. In the picture on the right it can be seen that a simple gas stove is used to fry the spring rolls.

Image F.1.6: Chả Giò sold on the streets in Hanoi

Chao Ga

This is a simple dish with which you can put almost everything you like in it and building a special soup any time from breakfast to supper. The main component is rice and can be added with chicken, egg, sea food, etc. For the preparation of this dish water needs to be boiled after which the rice is added, then it needs to simmer for about 20 to 30 minutes. The most common stoves that are used to prepare this dish can either be a gas or beehive coal stove for in the city. In the rural area they might use an open fire.

Image F.1.7: Rice soup sold in small restaurant in Hanoi

Rural area in the north

Most of the food presented can be bought in the city of Hanoi and places around the city. But there are some differences between the city and the rural area in terms cooking.

The context

There are some differences within the rural areas. Most of these differences are due to the height of the income. When the people are richer they move from cooking outside to inside where there is more convenience like lighting and tables to prepare the food. When people can afford to buy it, they will use multiple cookstoves like LPG or wood stoves which they will use according to their cooking task. The same habits can be seen here as in the city, for long cooking times wood- or coal stoves are used while for short periods the LPG stove is used as it provides more convenience. Some families also have an electric rice cooker when they can afford one.

Eating is usually done either on the ground or at small tables. Dishes are spread out on the table where everybody can take what they want and put it in their own bowl. Rice is usually eaten after the meal to fill the stomach and is rarely the main component of a dish.

Meals

Typical dishes for families consist of the following dishes:

- Plain rice
- 2 meat or fish dishes (boiled, grilled, steamed and or fried meat or fish)
- One vegetable dish (cooked or steamed)
- Soup
- Dipping sauces

Cooking times are dependent on the size of the family, and the complexity of the dish but on average it takes about 45 minutes to prepare the meal.

Image F.1.8: A pig being slaughtered on a farm outside Hanoi

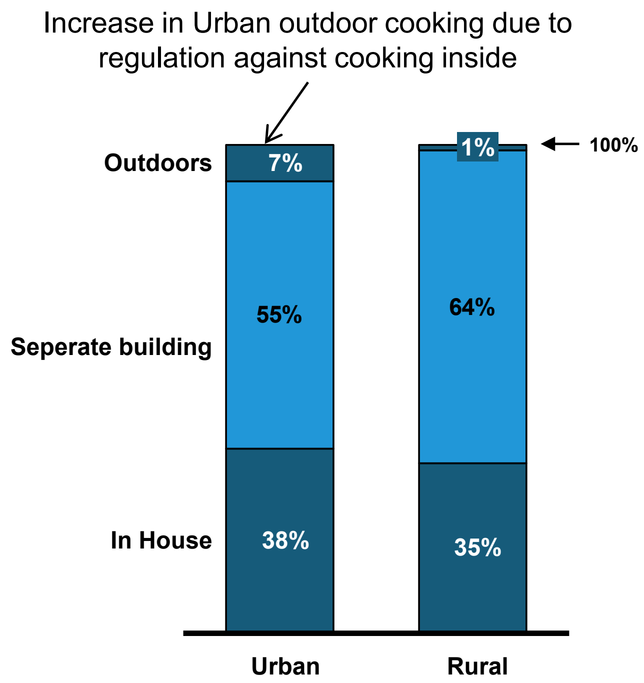
Image F.1.9: Picture of Vietnamese village in the North

Image F.1.10: Eating on the floor with the dishes in the center of the dining circle

Cooking habits & statistics

This analysis showed different traditional dishes which gives a good impression of the importance of food in the Vietnamese culture. From personal observations and literature research. The following statics will provide quantitative data on Vietnamese cooking traditions.

Graph F.1.1 shows the main cooking place of urban and rural households. Important to know is that when people use cooking equipment that produce toxic gases then it will be less harmful for their health when people cook outside. (cleancookstoves.org, 2012)



Graph F.1.1: Main cook place Vietnamese households

Ventilation conditions kitchens in Vietnam

Table F.1.1 below shows the ventilation conditions that were observed in different provinces in the North. They are further more divided by wealth and ethnic groups so a comparison can be made to see the influence of wealth on better living conditions. Because cooking on biomass fuels will always produce some toxic gases it is advised to have some sort of ventilation or having a chimney to reduce the risks of indoor air pollution. (SNV, 2011)

Statistics in the table below show that only 32.3% of the 736 kitchens that were observed in this research have a chimney. And the number of ethnic minorities and the poor having a chimney was significantly lower with 20% and 18.55 respectively.

If there is no chimney present having good air circulation can also reduce the effect of indoor air pollution. This number is much higher than the amount of chimneys with 71% on average of all the groups. Again poor and ethnic minorities have a slightly lower rate than households with more wealth.

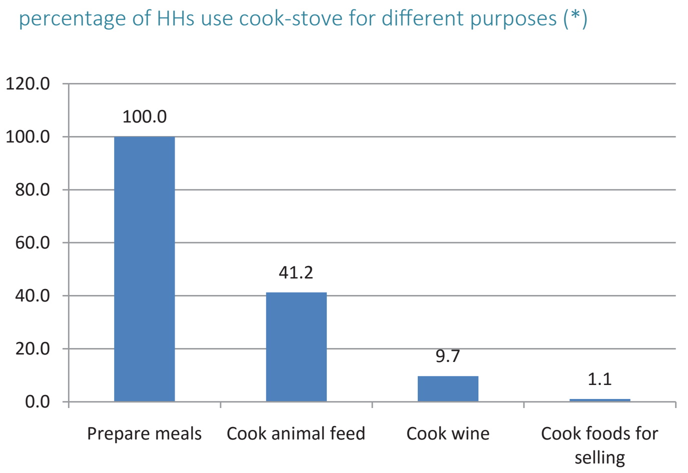
A very high number of the observed kitchens produce smoke, 79,2%. Again the poor groups have a higher rate of smoke as they use firewood and agricultural residues for cooking. The smoke could be less if there is good ventilation present or with the use of an advanced cookstove.

Categories		Having a chimney			Having air circulation window			Produce much smoke		
		Yes	No	Total	Yes	No	Total	Yes	No	Total
		%	%	Num	%	%	Num	%	%	Num
Province	Hanoi	37.4	62.6	238	79.8	20.2	238	59.7	40.3	144
	Nghe An	32.8	67.2	247	68.3	31.7	246	93.1	6.9	159
	Yen Bai	27.1	72.9	251	65.2	34.8	250	83.0	17.0	159
Wealth	Poor	18.6	81.4	86	52.9	47.1	85	94.6	5.4	56
	Better-off	34.2	65.8	650	73.3	26.7	649	77.1	22.9	406
Ethnic groups	Kinh	35.1	64.9	601	73.5	26.5	599	73.7	26.3	358
	Ethnic minorities	20.0	80.0	135	60.0	40.0	135	98.1	1.9	104
Total		32.3	67.7	736	71.0	29.0	734	79.2	20.8	462

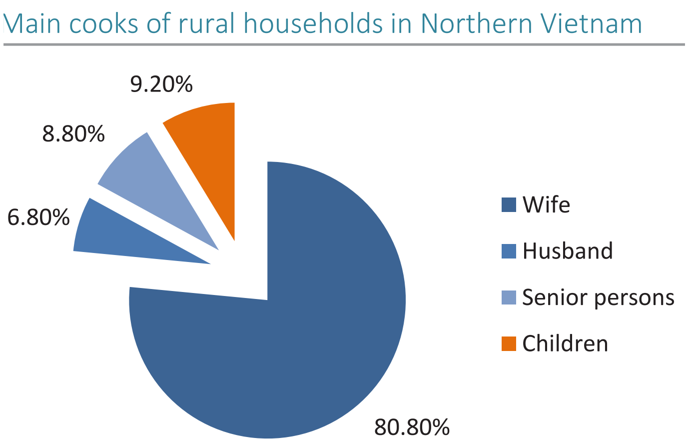
Table F.1.1: Ventilation conditions in kitchens of different segments

Cooking activities

Looking at the graph on the right household cooking activities are shown. It shows that every household uses their cookstove to prepare their meals, but also 41.2 % of them use it to prepare food for the animals. (SNV, 2011)



Graph F.1.2: Percentage of households that use their stove for different purposes



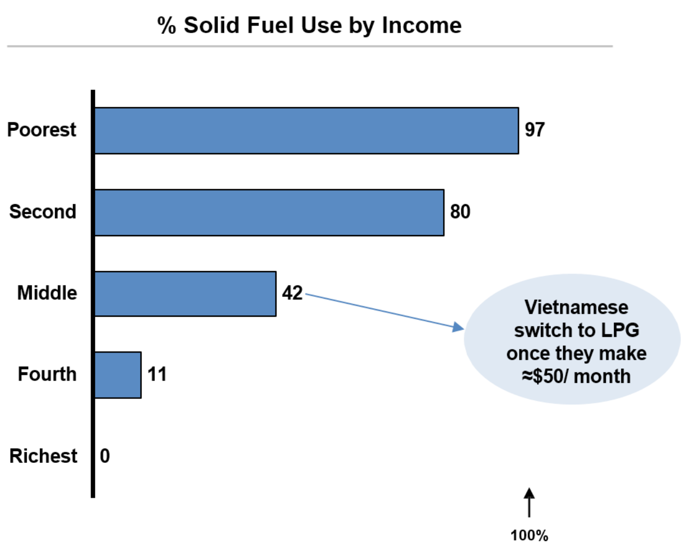
Graph F.1.3: Percentage of main cooks within rural households

Main cooks of rural households

Figure F.1.3 on the left clearly shows that the wife is the main cook in the north of Vietnam. Children also have to help out with cooking tasks, this is important to know as children are even more vulnerable for diseases caused by toxic emissions than adults. The research also tells us that households spend 2.6 hours for cooking divided into morning, noon and evening. Besides the health benefits an improved cookstove could improve their lives by shortening cooking time which make more time available for other tasks such as studying and relaxing. (SNV, 2011)

Solid fuel by income

Looking at the percentage of households that use solid fuel compared to their income it clearly shows the effect of wealth on people their cooking practices. Switching to alternatives such as the LPG stove brings a lot of advantages and ease of use. Firewood remains the main and preferable fuel source for rural people, especially the poor, mountainous and minority people. The reason is that firewood is locally available for free or at a reasonable price. It can be concluded that the introduction of improved cookstoves using biomass will be most beneficial to these disadvantaged groups. (SNV, 2011)



Graph F.1.4: Solid fuel use by income

APPENDIX F.2: STOVE TYPES IN THE VIETNAMESE MARKET

This appendix gives an overview of the most common stove types among Vietnamese households. It is common for people to have more than one stove and use them to complement each other. Each stove will be analyzed for its strong points and its drawbacks regarding its use.

- Beehive coal stove
- Electric cookstove
- LPG gas stove
- 3 stone fire (or open fire)
- Wood stove
- Wood/ saw dust stoves

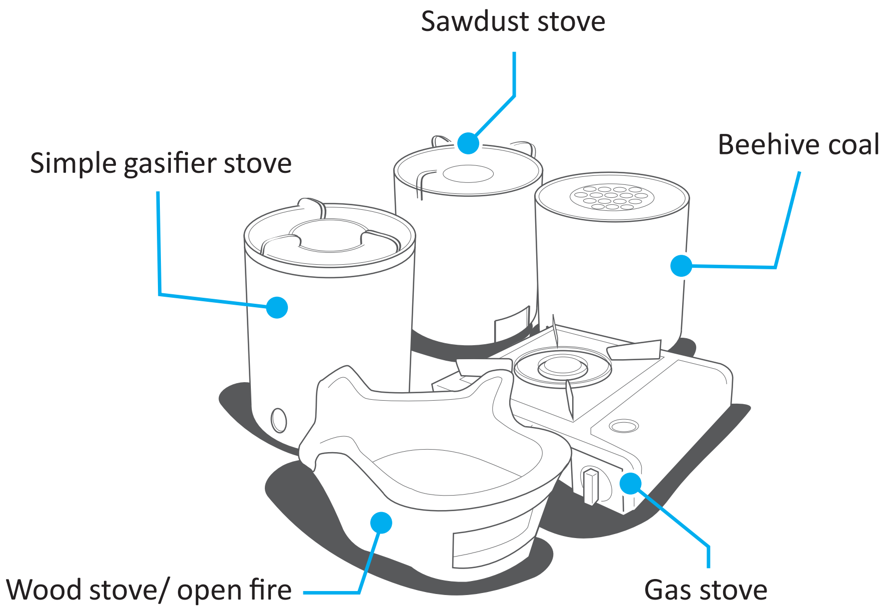


Image F.2.1: Schematic overview of different stove types within the Vietnamese market

Beehive coal stove

Beehive coal stoves are one of the most popular cooking methods used, especially in cities (see Figure F.2.2). The beehive cookstove has a cylindrical shape. It is made of heat resistant clay and covered by a thin zinc plate steel layer. At the bottom-side there is an entrance for air supply that can also be used to control fire and heat by depending on how far the slide is opened.

The beehive coal consists out of coal paste compressed in this shape. Prices of beehive coal stoves start from around 40,000 VND (less than 2€) for the cheapest version to around 120,000 VND (4,5€) for the most expensive one. As for the bricks, each brick of coal costs around 3.000VND (0,11€) and lasts for around 4 hours.

Positive

- Can boil 1 liter water in 9 minutes
- Can burn for almost 4 hours with a constant heat
- Suitable for big and smaller pots (depending on the stove design)
- The stove is portable and can be used outdoor
- The stove is cheap in operation and
- Fuel is easy accessible and can be delivered to people their door with an easy phone call

Negative

- Coal bricks are difficult to find in rural areas.
- Starting a brick is not easy and often electric starters or other fuels are used such as kerosene or ethanol
- The operation cannot be stopped, this means the entire brick has to be burned
- Since it is a short cookstove the body adopts a crouched position when cooking

Image F.2.2: Multiple stoves used outside a small restaurant in Hanoi

Image F.2.3: Beehive coal stoves with pot and special plier

Image XF.2.4: Electric starter for beehive coal.

Image F.2.5: Burned out beehive coal briquettes discarded at the side the street

Image F.2.6: Transportation of beehive coal by bike

Electric cookstove

The electric cooker forms a big contrast with the beehive coal. Obviously It can be used continuously and is easy to start and operate. There are a lot of reasons however for people not to buy or use their electric cookstove. The main reason is that electricity is relatively expensive compared to other alternatives. They are likely not to be used for boiling water but for quickly heating or frying dishes. Also they form the only direct alternative as gas stoves as they show a lot of similar characteristics in terms of operation.

Image F.2.7: Electric stove used in a small restaurant in Hanoi

Positive

- Can boil 1 liter water in 2.5 minutes
- There is no limit on the cooking time of the stove
- Can cook very fast and is easy to operate
- An electric cookstove does have any direct emission of gases
- Have a higher efficiency than LPG gas stoves
- Low maintenance as cooking equipment does not get black from the smoke

Negative

- Are quite expensive to buy ranging from 300,000 VND to 1,2000,000 VND
- Electricity is expensive for most people
- It does not heat as quickly as a gas stove
- Can be more efficient then a gas stove
- Does not support big pots
- An electric stove is not portable
- Are not portable
- Power black outs are common in Vietnam

Electric rice cookers are also frequently used by lower income urbanite. It is very convenient to operate and price ranges from 200,000 to 3,000,000 VND.

LPG gas stove

As soon as the middle class can afford to step over to a gas stove they will. It provides a lot of convenience for the user. But there is also a group that uses the gas stove only for short periods of time as it provides a lot of convenience. When they use it only for short periods of time a tank of 12 Kg last about 3 months. As with the beehive coal gas tanks have a well established distribution channel. With a simple phone call people can get a full container within half an hour.

Positive

- Can boil 1 liter water in 5 minutes
- People can start cooking almost instantly
- A gas stove produces almost no toxic emissions
- They are portable so they could be used outside and in areas where there is no electricity available
- The strength of the flame can easily be controlled
- Less important but it also gives status to people who are able to afford cooking on gas
- Low maintenance as cooking equipment does not get black from the smoke

Negative

- The price is the biggest issue for most people. A standard 12 Kg tank cost around 14 USD. This would buy you almost 140 beehive coal bricks
- The price of the stove is also higher compared to other stoves

Three stone fire

As with most of the cooking techniques the way of operating determines how well the task is accomplished. According to (SNV, 2011) the three stone fire can be used relatively clean when operated in a proper manner. When it is not properly used it can also be inefficient, wasteful and harmful to people their health. The reason for this is because people tend to make an overly large fire or leave smoking wood under a simmering pot while attending to other work. There are a lot of different types for this open fire, a lot of the time something like an iron bar is used instead of stones or clay. Iron-bar cook-stove lasts for long time, from 5 to even more than 20 years. The price is relatively low ranging from 50,000 VND to 100,000 VND depending on the size and the amount of iron consumed. It is available in local market and iron-warehouse with normal sizes. Today most people order at welding workshops because they can have tailor-made one at any size that fit their needs.

Image F.2.8: Typical LPG gas stoves in a small restaurant

Image F.2.9: LPG gas tanks sold in a shop located in Hanoi

Image F.2.10: Three stone fire

Image F.2.11: Young children exposed to toxic gas from a open fire

Wood stove

This type of stove is highly popular in the rural area as fuel is often widely available for free. There are many different types of these stoves where some people even make them themselves. The stoves are often made from clay or ceramics or are based on a rocket stove design. This means that fuel is loaded from the bottom and the heat and flame is directed to the pot through a combustion chamber.

Positive

- Simple versions of this type of stove, made from ceramic or clay, cost around 40,000 VND
- Fuel can be found freely around the house or purchased for around 50,000 VND which is enough for two days of cooking
- They are suitable for a lot of different materials to use as a fuel
- These stoves or open fire have an additional function to heat the house
- The stove can be portable to be used outside where the ventilation is better
- Can be installed inside with a small kitchen
- A chimney can be installed for better ventilation and drain of toxic gases

Negative

- Can boil 1 liter water in 13 minutes
- Even improved wood stoves will produce a lot of toxic smoke
- Cooking takes more time compared to other stoves
- Wood has to be added regularly during the cooking process
- Children also operate these stoves which

Image F.2.12: Simple wood stove made from clay

Image F.2.13: Cookstove uses wood based on the rocket stove principle

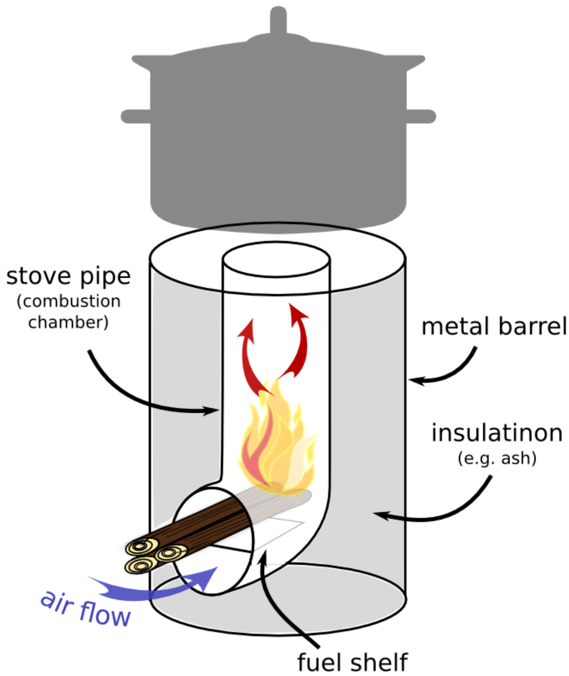


Image F.2.14: Rocket stove principle

Image E.3.1: Some of the stoves used in the analysis

Ace 1 cookstove

$80-150 (micro financing for development markets)

Features:

- Suitable for wood and other biomass fuels
- Fan control, forced draft primary/ secondary air
- Dimensions (l/b/h): 330/330/350 mm, 4.6 kg
- Thermoelectric generator
- Can charge electric devices with 5V USB outlet

Materials

Powder coated mild steel base, Stainless 304 body and inner, 20mm refractory ceramic tiles in the burning chamber, mild steel pot rest top

Philips HD4012

$89

Features:

- Suitable for wood and other biomass fuels
- Fan control, forced draft primary/ secondary air
- Dimensions (l/b/h): 330/350/330 mm, 4.6 kg
- Rechargeable battery
- Adapter

Materials

- Injection molded base
- Combustion chamber made of ceramic tiles

Mimi moto stove

$35

Features:

- Suitable for pelletized fuel
- Forced draft & secondary primary air
- Fan control
- Removable reactor with special tool
- Handles at the side for moving the stove
- Rechargeable battery 3000mAh or 5000mAh

Materials

- Stainless steel powder coated body
- Injection molded feet & control box
- Stainless steel reactor

Oorja pellet stove

$23

Features:

- Over 400,000 units sold (most successful stove on the market)
- Suitable pelletized fuel
- Forced draft primary air
- Fan control (2 positions)
- Rechargeable battery
- Adapter

Materials

- Stainless steel
- Combustion chamber made of ceramic tiles

Biolite basecamp

$299.00 (less for development markets)

Features:
- Suitable for wood and other biomass fuels
- Fan control, Air is added at the middle
- Dimensions (l/b/h): 460/445/485 mm, 9.1 kg
- Thermoelectric generator
- Can charge electric devices with 5V USB outlet

Materials
- Stainless steel powder coated base
- Injection molded box for electronics

Biolite camp stove

$130

Features:
- Suitable for small twigs and pellets
- A vortex of air is created at the top
- Dimensions (l/b/h): 178/152/220 mm, 0.96 kg
- Rechargeable battery, thermoelectric generator
- Can charge electric devices with 5V USB outlet

Materials
- Stainless steel powder coated base
- Injection molded box for electronics

Envirofit M5000

$ 129,95

Features:
- Suitable for wood and other biomass fuels
- Natural draft primary air
- Dimensions (l/b/h): 320/320/280 mm, 4.2 kg
- Handles at the side for moving the stove

Materials
- Mild steel powder coated body
- Wood handles
- Ceramic reactor
- Insulation material

Envirofit G-3300

$ 99

Features:
- Suitable for wood and other biomass fuels
- Natural draft primary air
- Dimensions (l/b/h): 275/261/288 mm, 5.7 kg
- Handles at the side for moving the stove
- Special tray for placing wood so air can flow underneath

Materials
- Mild steel powder coated body, cast iron top
- Wood handles
- Ceramic reactor
- Insulation material

3 models of Paul Olivers stove

$44 to $78.76 depending on the version

Features:
- Suitable for rice husk fuel
- Batch operated TLUD design
- Three models: 2-4, 2-10 & 20-40 kg fuel/ hour
- Forced primary air with an axial fan
- Focus on the Vietnamese southern market

Materials
- Stainless steel (sheet metal parts)
- Stainless steel tubing

Champion stove

$ 37 prototype phase

Features:
- Suitable for wood and other biomass fuels
- TLUD Natural draft primary & secondary air
- Separate pot support on tripod
- Separate burner to be placed on top

Materials
- Stainless steel (sheet metal parts)
- Wood handles and legs

Awamu quad stove

$ 11-16

Features:
- Suitable for wood and other biomass fuels
- Batch loaded
- Dimensions (l/b/h): 300/300/500 mm, 4.0 kg
- TLUD Natural draft primary & secondary air
- Separate burner to be placed on top
- Four leg support for stability, portability and safety
- Adjustable vent to control flame heat

Materials
- 24 Ga. galvanized metal sheet
- Wood
- Bolts and nuts

Awamu troika

$16-20

Features:
- Suitable for wood and other biomass fuels
- Batch loaded
- Dimensions (l/b/h): 300/300/500 mm, 3.5 kg
- TLUD Natural draft primary & secondary air
- Separate burner to be placed on top
- 3-Wooden handles for stability, portability and safety
- Adjustable vent to control flame heat

Materials
- 24 Ga. galvanized metal sheet
- Wood
- Bolts and nuts

Mayon turbo stove

$ 30

Features:

- Suitable for rice husk fuel
- Semi continues operation
- Natural draft primary- secondary air
- 4 kg
- A ring structured holder provides excellent pot stability

Materials

- Galvanized steel (sheet metal parts)
- Mild steel tubing

Mayon turbo stove

$ 15-20

Features:

- Suitable for wood chips fuel
- Semi-continues operation
- Natural draft primary- secondary air
- 4 kg
- A ring structured holder provides excellent pot stability

Materials

- Mild steel (sheet metal parts)
- Mild steel tubing

Instove

60L $850, 100L $995, 41.5L $400

Features:

- Suitable for wood, pellets and other biomass fuels
- Attached chimney
- Pots are integrated in the design

Materials

- Stainless steel powder coated body
- Injection molded feet & control box
- Stainless steel reactor

Solar serve 3G clean cookstove

$20

Features:

- Focus on Vietnamese market
- Suitable for 15-20 cm biomass fuel pieces
- Rocket stove design
- Natural draft primary and secondary air
- Dimensions (l/b/h): 30 x 30 x 40cm weight 2.8 kg

Materials

- Powder coated mild steel parts

Philips Natural Draft Stove HD4008

$31

Features:

- Suitable for wood and other biomass fuels
- Batch loaded
- Dimensions (l/b/h): 310/310/320 mm
- TLUD Natural draft primary & secondary air
- Adjustable vent to control flame heat
- Three leg support

Materials

- Bottom coated steel, Upper body is made of galvanized steel, Combustion chamber and top are made of steel.

TERI SPT_0610

$20-30 (aimed target price)

Features:

- Suitable for wood and other biomass fuels
- Fan control, forced draft primary/ secondary air
- Dimensions (l/b/h): 330/350/330 mm, 4.6 kg
- Rechargeable battery 12V, 2.2 Ah Lithium-ion
- Adapter solar panel

Materials

- Carbon steel (sheet metal parts)
- Carbon steel tubing

Prime cylindrical biomass stove

$30

Features:

- Two separate cylindrical control valves for primary and secondary air
- Dimensions (l/b/h): 245/245/360 mm, 3.5 kg
- Suitable for dried biomass such as wood sticks (10-20 cm), briquettes, dry leaves
- Fuel consumption for normal use is 600 grams/hour
- Natural draft TLUD design

Materials

- Burning chamber and top part made from stainless steel, other parts are made from galvanized plates

Berkeley-Darfur stove

$10 (target selling price)

Features:

- Rocket stove
- Unique edged sheet metal design
- Dimensions (l/b/h): 370/170/300 mm, 5.5 kg
- Small fire box opening to prevent using more fuel wood than necessary.

Materials

- Stainless steel sheet metal parts
- Mild steel grade
- Wooden handles

Rocket works stove

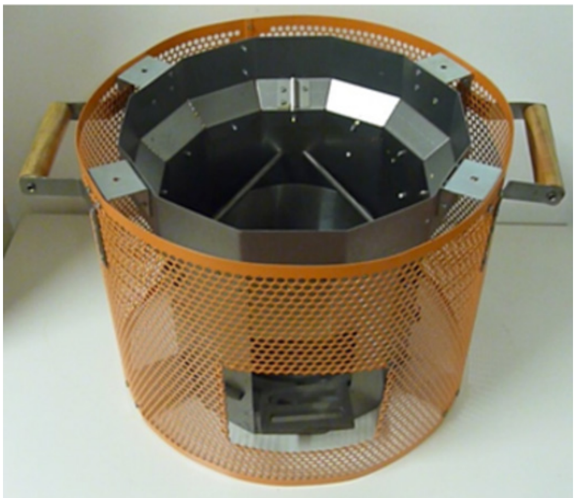
$35

Features:

- Cage around the reactor provides safety for users
- Suitable for multiple types of biomass fuel
- Side feed
- Natural draft primary and secondary air
- Dimensions (l/b/h): 240/240/270 mm, 3.0 kg

Materials

- Stainless steel
- Powder coated metal cage



Berkeley-Darfur Stove “Cool Mesh”

$ 18-35

Features:

- Cage around the reactor provides safety for users
- Suitable for multiple types of biomass fuel
- Side feed
- Natural draft primary and secondary air
- Dimensions (l/b/h): 813/432/305 mm, 5.0 kg

Materials

- Stainless steel
- Powder coated metal cage
- Wooden handles

Greenway Smart Stove

$ 25

Features:

- Rocket stove
- Works on all solid biomass fuels (wood, dry-dung, agro-residue etc.)
- Natural draft primary and secondary air
- Dimensions (l/b/h): 250/193/295
- Three leg support

Materials

- Steel and Aluminum with Bakelite Handles

Shengzhou Top Load Fan Stove

$20

Features:

- Top feed fuel design
- Batch/ semi continues operation.
- Fan assisted
- 260/260/370 mm, 5.7 kg

Materials

- Ceramic lined
- Mild steel powder coated
- Stainless steel

APPENDIX F.4: MARKET SEGMENTATION

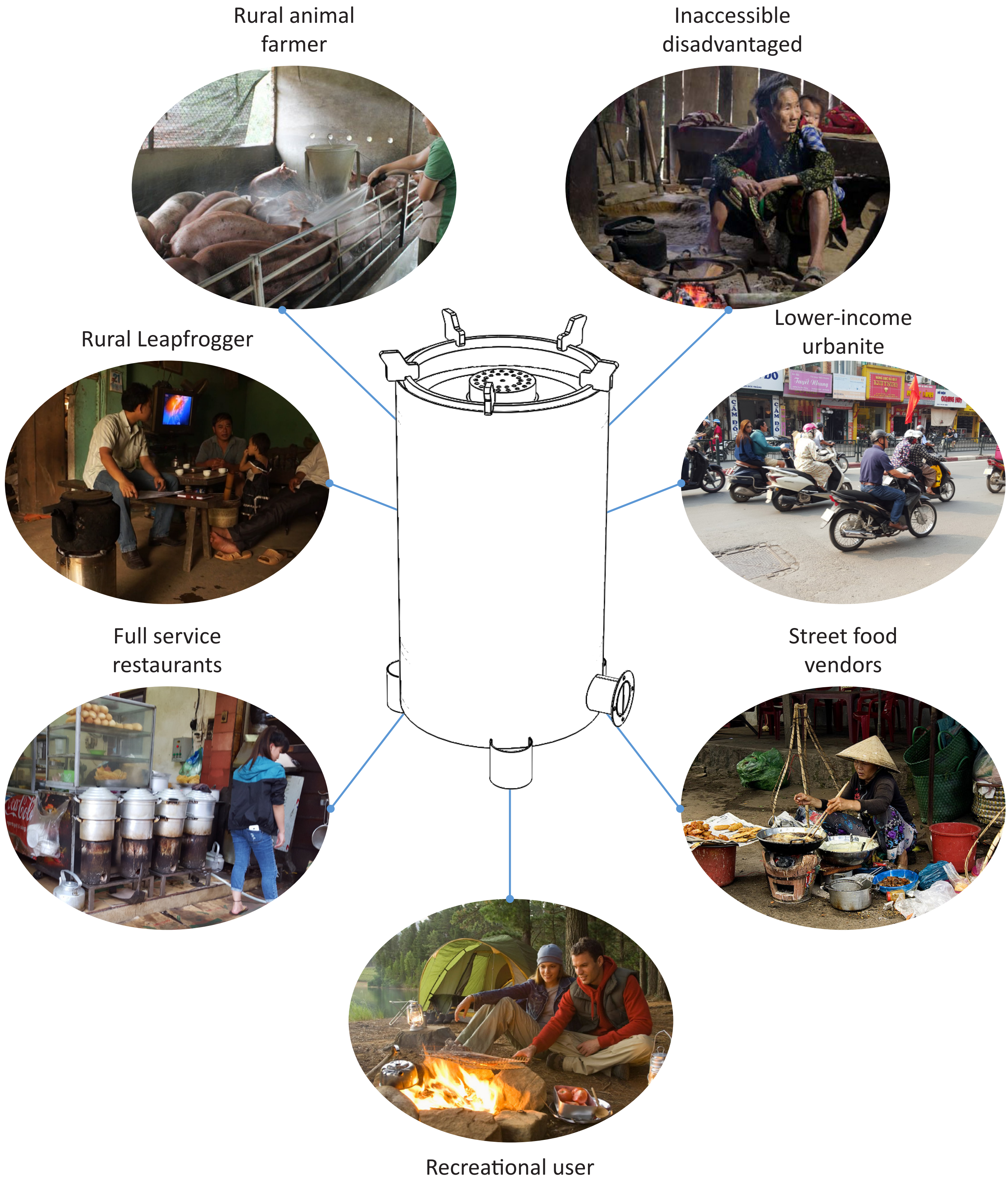


Image E.4.1: Seven market segments for a gasifier stove

	1 Rural animal farmer	2 Inaccessible disadvantaged
	• Has access to modern fuels such as LPG and Electricity	• Has limited or no access to modern fuels such as LPG ad Electricity and is not near roads • Primary uses biomass (wood and agricultural residue) • Use their current cooking device for heating the home
		
Size in Households	• 4.4 m (19% of population) • Cooking is primarily a task for the women.	• 2.8 M (12% of population) • Cooking is primarily a task for the women.
Profession	• Animal Husbandry and Farming	• Subsidence Farmers, Gatherers, Ethnic
Household Income	• Above Poverty Line	• Below Poverty Line
Cooking Device & Fuel	• Traditional Wood burning cook-stoves, Gas cookstove • Fuel: Firewood, LPG, Biogas	• Traditional: Fixed Cement cook-stove, 3-stone fire • Fuel: Wood, crop residue
Cooking Location	• Indoors in a separate building	• Mostly Indoors for heat in winter, maybe go to a separate building or outdoors in winter • No easy access to electricity
Cooking Frequency	• Two to three meals per day	• One to two meals per day
IAP Exposure	• Med	• High
IAP Awareness	• Med	• Low
Environment Impact	• High (Manure disposal)	• High (Deforestation)
Barriers to Switch	• Lack of Capital (81.2%) • Lack of construction area (21.2%) (Biogas User Survey 2011) • The man is typically in charge of large expenditures and a stove might not provide direct benefits for him	• Affordability • Access to financing • Awareness • Accessibility to modern fuels • The man is typically in charge of large expenditures and a stove might not provide direct benefits for him
Willingness to Pay	• Medium – hard to pay out of pocket	• Low, due to displacement costs from flooding
Purchase Drivers	• Fuel Savings • Ease of use • Perception	• Fuel costs • Ease of use

	3 Rural Leapfrogger	**4 Lower-Income Urbanite**
	• Has access to modern fuels but might not spend money on them in favor of portraying wealth through purchase of high cost electronics, etc	• Has access to modern fuels such as LPG and Electricity • Increasing costs has forced a higher usage of coal • Uses LPG for quick foods and electricity for rice cooker
		
Size in Households	• 4.6 M (21% of population) • Cooking is primarily a task for the women.	• 1.1 M (5% of population) • Cooking is primarily a task for the women.
Profession	• Farmers, Industry, Service & Salary Workers	• Service workers, industrial workers
Household Income	• Above Poverty Line	• Below or near poverty line
Cooking Device & Fuel	• Traditional fixed cookstove and Portable cookstove • Fuel: Wood, Crop Residue,	• Traditional Rocket cookstove • Fuel: Beehive Coal
Cooking Location	• Outdoors during summer • Indoors during monsoon season	• Outdoors during warm season • Indoors during winter, though not ‘allowed’
Cooking Frequency	• One to two meals per day	• Two to three meals per day
IAP Exposure	• High	• Med
IAP Awareness	• Low	• High
Environment Impact	• High	• Med
Barriers to Switch	• Affordability • Access to financing • Awareness • The man is typically in charge of large expenditures and a stove might not provide direct benefits for him	• Affordability – All would prefer LPG if they could afford it
Willingness to Pay	• Low – med, some can afford ICS while others will require financing or heavy subsidies	• Med – will pay when alternative fuel prices increases
Purchase Drivers	• Ease of use • Perception	• Fuel costs • Ease of use

	5 Full service restaurants	6 Street food vendors
	• Has access to modern fuels such as LPG and Electricity • Increasing costs has forced a higher usage of coal • Uses LPG both for quick foods and complete dishes • Need multiple stoves or areas for cooking with multiple pots	• Has access to modern fuels such as LPG and Electricity • Can only use portable stoves, small LPG tanks are even more expensive than the 12 L tanks. • Can use one stove, but depending on can be using multiple • Popular for eating breakfast
		
Market size	• Market value in 2012 , 18,477.6 million USD	• Market value in 2012 , 11,961.9 million USD
Cooking Device & Fuel	• Traditional fixed cookstove and Portable cookstove • Fuel: LPG, electricity and Coal	• Traditional portable stove • Fuel: Beehive Coal, LPG (small)
Cooking Location	• Outdoors just in front of the restaurant • Indoors mostly during monsoon season	• Outdoors on the streets • Build up their business at the beginning of the day and pack everything up at the end
Cooking Frequency	• The whole day	• The whole day
IAP Exposure	• Low	• Med
IAP Awareness	• Low	• Low
Environment Impact	• Low	• Med
Barriers to Switch	• Affordability • Awareness • The convenience is lower than current alternatives • Batch operating stoves might not last long enough • Change in cooking habits	• Affordability of investment • Awareness • Change in cooking habits • Batch operating stoves might not last long enough
Willingness to Pay	• Low – med, if they can save enough on the fuel cost it gets interesting for them	• Low
Purchase Drivers	• Savings on fuel costs	• Regulation that banned the beehive coal in certain areas • Fuel cost savings

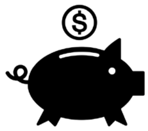
7 Recreational users

- Would use a stove as this for out-door activities such as camping or on a pick-nick
- Expect high quality and durability from the product
- Efficiency and low emission values are of lower concern as the stove is only used on special occasions.
- Stand alone solution for electricity is a must

Market size	• 4.6 M (21% of population) • Cooking is primarily a task for the women.
Cooking Device & Fuel alternatives for out-side cooking	• Gasoline stoves, portable gas stoves, BBQ • Fuel: LPG, coal, Gasoline
Cooking Location	• Anywhere outdoors where people want to cook when being outside.
IAP Exposure	• Low
IAP Awareness	• Low
Environment Impact	• Low
Barriers to purchase	• Price • No real need and will therefore not use it often • Pelletized fuel should also be car-ried
Willingness to Pay	• Low – med, similar products in the market are sold for over between 150 and 300 USD.
Purchase Drivers	• Unique experience compared to other outdoor cooking equipment

APPENDIX F.5: PRIMARY USER NEEDS ASSESSMENT IN VIETNAM

This chapter will summarize the finding from the previous analysis into quantified data to asses how the gasifier should fulfill the primary user needs. According (GHTC 2014) eleven primary user needs should be fulfilled for higher adoption rates among users. A lot of stoves that have currently been developed focuses on fulfilling only specific requirements. For example, only focusing on a high efficiency but ignoring the usability. Only when all the requirements have been fulfilled (or at least carefully considered) has the product a good chance of being successful in the market. All these user needs will be analyzed on how they apply to the Vietnamese market.



1. Fuel savings

Is the amount of fuel currently needed adequate for the cooking task?
In appendix F.1 different typical Vietnamese dishes have been analyzed. From this research it can be concluded that different cooking methods are being used for the preparation of one dish. Therefore, this is dependent on the type of fuel that is being used and the cooking task. The table below shows a comparison between different types of fuel and stoves that are commonly used in Vietnam, with the most common cooking tasks.

Type of cookstove	Fuel per batch	Fuel price (VND)	Boiled water per batch (liter)	Time to boil one liter of water	Total time per batch	Cost per liter of water (VND)	Price of the stove (VND)
CCS gasifier	0.6 Kg of wood pellet	2,100	12	2’10’	45’	105	380,000
Beehive coal	1 coal briquette	3,000	20	9’	180’	150	120,000
Gas	Standard tank of 12 Kg	300,000	760	4’9”	-	395	800,000
Electromagnetic stove	73.46 kWh	2,141	760	2’23”	-	207	300,000

Table F.5.1: Cost comparison between different stove. Information provided by CCS

A batch operated gasifier should not compete directly with the beehive coal as it does not last the same amount of time. But compared to the other cooking methods the gasifier does boil water faster and is a lot cheaper. This however does not take into account the time it takes to start the gasifier and the amount of fuel that is being wasted by inexperience of the user.

How much fuel is currently being used for the different cooking tasks?
Different cooking tasks require different power modes and durations of the stove operation. For the Vietnamese market the following cooking tasks are most common:

- Boiling relative small amounts of water for tea, rice or steaming vegetables and meat, this is done with high power mode
- Simmering pots near boiling temperature for soups or other dishes that require longer cooking times this is done in low power mode
- Frying of eggs, meat or vegetables this is done with medium power mode

How much fuel is being saved by using the gasifier and thus how much money do they save compared to old cooking methods?
Looking at the table above it clearly shows how much people can safe fuel when investing in a gasifier stove. This is especially true when using the gasifier just for water boiling purposes. For boiling 5 liters of water you would safe 1,450 VND compared to using a LPG stove.

2. Flexibility with different types of fuel

What types of fuel are available in the target market its region?
In the market analysis six different segments have been identified. For most of these segments LPG and coal is widely available but costly. When looking at the segment, the "inaccessible disadvantage" which is most in need for a cleaner cooking solution, wood and agricultural waste is often freely available for them.

- Which types of fuel can be used?

The gasifier stove of CCS is designed for pellet type fuels. Though pellets are not widely available in Vietnam they do provide significant advantages over other types of biomass fuels. Other types of gasifiers in the market mainly focus on four specific types of biomass fuel:

- Rice husk
- Straw
- Small twigs and branches
- Pelletized fuel

Each type of gasifier will operate to its maximum capabilities with respect to stability, gas quality, efficiency and pressure losses only within certain ranges of the fuel properties of which the most important are:

- Energy content
- Moisture content
- Volatile matter
- Ash content and ash chemical composition
- Reactivity
- Size and size distribution
- Bulk density
- Charring properties

Which types of fuel does the user want to use?
This is dependent on the price, availability and usability. For example, in some areas in Vietnam rice husk is abundantly available at some periods of the year. For this reason, special rice husk gasifiers have been developed, however because this fuel is not available throughout the year it does not provide a complete solution for these consumers. Another example is that besides agricultural waste twigs, branches, leaves etc. are also being used. This is collected around the house or in the forest throughout the year. The disadvantage is that it is not a very suitable fuel for gasification because of the high moisture content and distribution inside the gasifier.

3. Reduction in emissions

What are the acceptable values of toxic gases emitted during the cooking process?
From the analysis in chapter 1.2.1. CO and PM2.5 are the most harmful and toxic products produced by incomplete combustion. If a gasifier stove wants to be classified as Tier 4, the highest scale (see appendix E.1) then the maximum emission value of CO is 0.42 g/min and of PM2.5 is 2 mg/min for indoor. Besides this classification WHO sets emission rate targets for household fuel combustion (not only focused on developing countries) which are even lower.

Recommendation	**Emission rate targets**	
Emission rates from household fuel combustion should not exceed the following emission rate targets (ERTs) for PM2.5 and CO.	PM2.5 (unventi-lated) PM2.5 (vented)	0.23 (mg/min) 0.80 (mg/min)
	CO (unventilated) CO (vented)	0.16 (g/min) 0.59 (g/min)

Table F.5.2: WHO guidelines for indoor fuel combustion PM2.5 and CO

Is the emission currently emitted by advanced cookstoves within acceptable boundaries?
The latest prototype has not been tested on its emission values. But it can be estimated based on the results written in the testing report of the 2014 prototype. The average emission values of three tests of CO indoor was 0.374 g/min and for PM2.5 indoor it was 6 mg/min.

4. Cooking time

Are the end users satisfied with the speed of their current cooking process?
Depending on what stove Vietnamese people use the boiling time for their water will be different. They know what to expect from a beehive coal or three stone fire but will always want to trade for an LPG stove if it was offered for the same price. Therefore, it can be assumed that faster cooking times are desired for these segments.

What time is acceptable for boiling 5 liters of water?
Looking at LPG stove and a typical three stone fire:

- A typical LPG gas stove can boil this amount of water within 23 minutes
- An average 3 stone fire can boil this amount of water within 26:42 minutes

This means that the cooking time will roughly be the same and the gasifier could have the same performance or better. Of course it has to be taken into account that the gasifier and 3 stone fire requires some preparation before you can start using it. Depending on how you start the gasifier it will take up to 10 minutes before you can start cooking.

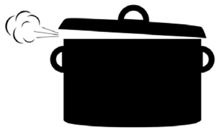
- What are the demands for regulating the turn down ratio?

Turn-down ratio is considered to be an important feature by users as this makes a gasifier very similar to the way a LPG gas stove is being used. By using a gasifier in dim mode the users are able to save on its fuel consumption when the stove is not being used for cooking or when dishes are prepared that do not require a lot of heat. Having the option to increase the power to boil water in minutes, is also an important feature as users should not be expected to wait hours before their meals are ready.

5. Local food preparation

What are the user's customary cooking practices?
As discussed in appendix F.1 the Vietnamese cuisine is very diverse and many different stoves are used complementary to each other. The gasifier should be able to cook in a manner equal to or more efficient than the traditional stove.

Is the gasifier cookstove compatible with the user's customary cooking practices?
Using the gasifier cookstove will require a behavioral change from some users. Although this is not ideal for adoption of a new technology, it seems inevitable. For batch operation stoves users have to know ahead the duration of the cooking task they want to perform; this is not the case with LPG or open fires in which more fuel can be added easily.



6. Compatibility with local cooking equipment

What local cooking equipment is being used?
The most important criteria for the end user is that their pot or cooking instrument is compatible with the stove both in size and stability. In Vietnam the cooking equipment ranges from:

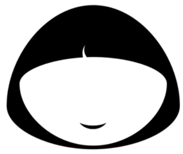
- Small pots/teapots of 14-16 mm diameter
- Mid-size pots of 20-22 mm diameter
- Big pots of 26-35 mm diameter

Is the current prototype compatible with this equipment?
Stove compatibility can be assessed both with size and stability. The current gasifier has multiple pot support whit different heights. For larger pots it is desired to lift the pot slightly higher as this gives the flame more space to expand over a larger area. For smaller pot you want the pot/pan closer to the flame so it has no chance of escaping from the sides.

7. Maintenance

How much maintenance is expected of the user to do by them self?
Looking at the stoves that are used in the Vietnamese market it can be observed that the user does not perform a lot of maintenance. Most of the cooking devices are dirty just like the cooking equipment that are being used. From interviews one of the reasons for this is that stoves like the beehive coal or rocket stoves make it inevitable that everything gets dirty. However, this does not mean that they do not dislike it and are willing to put more effort into it if the stoves do not get completely dirty after just a few times using it.

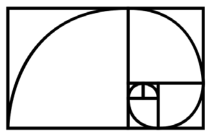
Does the current prototype need a lot of maintenance for it to function well?
The current stove needs some maintenance, after each operation the char has to be emptied from the reactor and some spills from food preparation might need to be cleaned from the surface. Other maintenance like char on pots and the burner are more difficult to remove. Eventually this can decrease the stoves efficiency and performance which contributes to the user their abandonment of the stove.



8. Ease of use

Can the current prototype be left unattended?
One of the greatest advantages of the beehive coal is that it burns at a constant rate for almost four hours without the need for a user to monitoring the process. For the gasifier there are some dangers, when the gasification process is started it produces combustible gases which are directly used for cooking. However, in the rare occasion that the flame goes out, these toxic gases are emitted in the air which can be very dangerous for users.

Does the user know what to do if the flame is unstable, yellow (incomplete combustion)
Carbon monoxide and particulate matter always form when fuel and air do not completely mix, and complete mixing does not occur in stoves with natural draft. The orange color of a flame comes from the radiation of particulate matter (soot) within the flame. Blue flame results from the reaction of carbon monoxide to produce carbon dioxide. So, colored flames indicate that PM and CO are reacting.



9. Aesthetics

Do current cookstove designs appeal to the consumers?
Aesthetic appeal of an improved cookstove is an important motivation for many households to purchase improved cookstoves. Looking at the different stoves in the Vietnamese market it can be noted that a lot of polished stainless steel is used or paint coatings from the basic color palette. Most of them have a standard cylindrical shape which provides opportunities to create something closer to the Vietnamese culture.

What does the end user consider as aesthetically pleasing within household products?
Vietnam is rich in traditional and natural production processes. It is home to over 2000 craft villages, whose traditions and histories are translated into their handcraft products. Until now most of the stoves are influenced by their industrial revolution without much attention this these traditions.

10. Affordability

What do they expect from the cookstove considering the amount of money they pay for it?
People in Vietnam are considered to be cost sensitive. Because a large part of the people from the target group live under or just above the poverty line, investing in an advanced cookstove is a big investment for them. According to literature (Vahlne & Ahlgren, 2014) people tend neglect advantages like fuel wood savings, shortened cooking time and pot size compatibility when the price is too high making the initial investment the most important factor for their decision.

How much is the user willing to pay for a well-functioning gasifier cookstove?
From research it is determined that people are willing to pay no more than 17 USD. People that have owned a gasifier stove in the past might be more skeptical when they have a bad experience and need to convinced of the stove its performance. Besides the price people need to be convinced by a demonstration of the gasifier.

11. Safety

Is a gasifier cookstove safe to use?
Safe operation of the gasifier is important for users. Not only do adults interact with the stove but also children sometimes have to use it. The following factors are important regarding its safety:

- Tipping
- Surface temperature
- Heat transmission to the surroundings
- Handle temperature

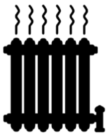
Burns, scalds and cuts are the most common safety concerns that result from stoves with improper safety precaution. For this reason, WHO took safety up in their Tier scale of performance see paragraph E.1.

What parts of the cookstove can be improved regarding its safety?
The following features of the gasifier can be improved regarding its safety:

- Placing the burner
- The surface temperature of the body
- Preventing the flame to go out shooting toxic syngas from the burner
- Removing sharp edges

APPENDIX F.6: SECONDARY USER NEEDS

Besides these primary user needs there are some end user needs that are unique for certain market segments. This section will give a short overview of the needs for certain areas.



1. Space heating

In some areas a three stone is placed in the middle of a house to provide heat for the home, giving it an extra function besides the use of just cooking. This is especially true for the inaccessible disadvantaged in the north were temperatures go below zero in the winter. To be able to implement a gasifier for this group it would be important to also use the stove as a heating device, otherwise they still have to rely on an open fire as their heat source.

2. Insect repelling

Another benefit from open fires is that it might prevent diseases transmitted by insects. There is some evidence suggesting that smoke from fires repel insects such as mosquitoes. One of the diseases occurring in Vietnam is Dengue fever. As there is no medicine against this disease the best way to avoid getting sick is to prevent getting bitten. The mosquitoes are most active during the summer and in the south of Vietnam so it might not pose a major issue eliminate this feature.

3. Portability

Most of the advanced cookstoves that have been developed are portable, which means that they can be moved around the house to any desired location. In Vietnam it is not uncommon to move their cooking practices outside when the weather and temperatures allow it. Portability is considered a more important feature in climates with large temperature differences throughout the year. For segments such as the street food vendors, recreational user and inaccessible disadvantage the feature is an important trait.

4. Provides light

Also looking at the lower income segment, it has been reported that one of the obstacles for the acceptance of clean stoves is they do not give off light such as traditional cookstoves. (Kshirsagar & Kalamkar, 2014) Therefore, these people would have to rely on other alternatives to provide light which might bring additional cost with them for the user. Some other stoves such as the Ace 1 provide LED light accessories which can be charged with the electric output of the stove.

APPENDIX F.7: LIST OF REQUIREMENTS

This list of requirements is compiled through identifying the processes in which the gasifier cookstove has to operate and the people who are going to use it.

Performance

Speed

- The stove should be ready for cooking within 10 minutes for experienced users.
- New users should get the gasifier ready for operation within 15 minutes.
- Lighting of the fuel should be made easy using other biomass fuel or starting fluids such as alcohol.
- 5 liters of water should be boiled within 23 minutes (excluding the time it takes to prepare the stove).

Capacity

- For batch operation: capacity for biomass should sufficient to cook continuously for 45 minutes to one hour on maximum power.
- For continues operation, the stove should be able to cook for 60 minutes without refueling.

Strength

- The reactor tube should withstand a drop from 2 meter.
- The gasifier main body should withstand a drop from 1 meter.
- The burner should withstand a drop from 1.5 meter.

Gasification & combustion

Gasification

- The type of gasification should be TLUD top lit updraft.
- The produce gas should contain high amounts of CO and H2 and low amounts of CO2.
- The gasification process should avoid unexpected interruptions.

Turn down ratio

- The turn down ratio should be as high as possible, meaning it should allow the user to adjust the amount of gas that is being produced while keeping the same quality of the generated gas.

Combustion

- Stoichiometric combustion should be achieved as close as possible.
- A minimal thermal efficiency of 45% should be achieved for HPP and LPP.

Environment

- The gasifier should withstand environments with high humidity ranging from 60 - 80% throughout the year, with an average temperature of 30 degrees Celsius. (weather-and-climate.com, 2016).

During transport

- The product should be able to be transported by motorbike. Everything that can be put on, or hang around a motorbike is transported that way.
- The product should withstand heavy bumps during transport.

During usage

- The stove should fit in the Vietnamese context and will be used inside as well as outside home environments.
- The product should be able to fit in the current cooking environment and should take the cooking equipment into account.
- Some parts of the gasifier such as the reactor will heat up and reach maximum temperatures of about 900-1300°C degrees.
- The gasifier should withstand wet and dusty environments.
- The gasifier should have minimum space for dirt accumulation.

Durability

Electronics

- Electronic components should be protected from any moisture or dust.
- The electronic components should work on low voltages (12V) and current (<1A).
- Most of the product its components should be able to withstand daily use for 10 years under normal conditions. Normal conditions can be identified as:

- Not exceeding the maximum amount of biomass fuel that is allowed.
- Suitable for the use of biomass fuels only, pellets are preferred.

Maintenance

- Parts that are likely to become dirty during cooking should be cleaned easily. Spillage should not be able to enter gaps that are inaccessible without taking the gasifier apart.
- Parts that have a lot to endure such as the burner should easily be easily replaceable.
- The entire gasifier should be able to get repaired. Therefore, permanent fixtures such as welding should be avoided for critical components.

Production costs

- Based on market research, the product should be sold for $ 17 dollars, which means production can only be as low as $9 dollars.
- For the first batch the product can be sold for a higher price, but will not appeal to the majority of the market.
- The use of locally available materials is preferred.

Transportation

- In Vietnam a common way of transportation is by motorbike, therefore small quantities of stoves should be able transportable by motorbike.
- Larger numbers of stoves should be able to be conveniently stacked onto each other in a truck.

Packaging

- The packaging should protect the product from outside damage such as surface scratches during transport.
- The packaging should communicate the functionality and benefits of the product that is inside.
- The maximum width of the packaging should not exceed more than 1 cm from the maximum diameter of the gasifier.
- Parts that stick out should preferable be detachable and be installed by the consumer.
- The price of the packaging cannot exceed more than 0.30 dollar per piece.

Batch size

- Production partners should be able to produce 500 units within 2-3 months.
- Production partners for a larger scale should be able to produce the 10 000 - 20 000 units per year.
- The gasifier design should allow for setting up a special production line.

Production facilities

- The gasifier should be able to be produced using low investment mass production techniques. It is possible that for the first batch cheaper production techniques are used.
- Investment in special tooling will be necessary but reliable calculations should determine the choice.
- When screws and bolts are used, only one type is preferred within the entire product.
- The design of the gasifier should be producible by local manufacturing shops.

Dimensions and weight

- The product should be easily transported between different location e.g. street, kitchen, and patio.
- It the design has parts that are sticking out, it is desired to be easily assembled by the user. In order to decrease the packaging size.
- The weight of the gasifier should be kept low to decrease transportation cost and allow for easier handling.
- The weight should not affect the stoves its stability.

Shape, color, and finish

- The stove can be made from stainless steel, because of the resistant properties to the high humidity in Vietnam.
- Vietnamese people seem to have a preference for polished steel products.
- A coating can be used to make the product more resistant to environmental impacts and to have a more appealing look for the consumers.
- The gasifier should have a shape that is appealing to the Vietnamese market and sets is apart from the other products in the market.

Materials

- Stainless steel should be used for most parts that are subject to high temperatures and environmental influences.
- Cast iron is a good alternative for parts that should withstand high temperatures.
- Production cost should be as low as possible it, so both material investments and tooling investments should not exceed the aim of

Product life span

- The lifetime of the gasifier should be at least 10 years.
- The set-up of the gasifier is to have a modular design. It is reasoned that parts can be replaced separately, without having to replace the whole gasifier stove itself.
- Upgrades of new designs can be sold to replace the older modular parts. In this case backward compatibility is important.

Norms and standards

- The gasifier should conform with the WHO guidelines for indoor air emissions.
- The gasifier should score TIER 4 for efficiency, total emission, indoor emission and safety

Reliability

- It should absolutely be avoided for the gasifier to produce toxic gas without burning completely.
- Flame blow off is also a very undesirable effect which should be avoided.

Storage

- The product should be as small as possible when stored. Parts that stick out should preferable be detachable and be installed by the consumer.

Testing

- The stove should be tested through a water boiling test (WBT) by a certified external party so it get an official certificate.
- Results of this test should confirm that the stove meets TIER 4 requirements.

Safety

Heat

- The outside surface of the gasifier should not exceed 43 °C according to ISO DIS137321 (Iso.org, 2016)
- The electronics should be isolated and sealed to prevent short circuiting by moisture.

Social and political implications

- The stove should appeal to governmental parties or investors to get them involved in the set-up of this stove program.

Installation

- Minimal installation of components should be required by the user.
- Instructions that come with the stove should kept simple and clear for people to understand.
- The design should prevent the users from misuse or wrong installation of the parts.

APPENDIX G: DEVELOPMENT

APPENDIX G.1: BURNER DESIGN PARAMETERS

The purpose of a gas burner is to transform gas into useful heat, which is to be absorbed by an object like the cooking equipment. To obtain this purpose involves many variables; the design of the injector, the passageways of the syngas and secondary air are part of this complex problem. In general, a burner must have the following characteristics:

- Be controllable over a wide range of turn-down ratios without flashback or outage.
- Provide a uniform distribution of heat over the area that needs to be heated
- Be capable of completely burning the gas
- Ensure that there is no lifting of flames away from the ports
- Help with the ignition by cross lighting, with the flame traveling from port to port over the entire burner rapidly
- Be of solid construction to withstand severe heating and cooling during all the life of the appliance
- Concentrate the flame in the center so less heat is lost at the side of any pan or pot.

Current issues
From the previous analysis some challenges for designing a burner for a gasifier were identified. Unlike LPG or other types of fuel, the syngas from a gasifier has to be created in high temperature environments. Because the generated gas has such high temperatures it makes it quite unstable to where in the gasifier it will ignite as only a small amount of oxygen can start the combustion reaction. In order to have high efficiency it is important to control where the syngas is burned, more specifically it should be burned on top of the burner outside the gasifier. When the gas is burned inside of the gasifier it has two unwanted effects. The first is that it heats up the burner and the other parts of the gasifier through convection. This causes the material to deteriorated faster. The second issue is related to the first effect, because when the energy is wasted on heating the burner and other parts of the gasifier the efficiency decreases. If the flame would burn on top of the burner this energy can be used for the cooking task, and less fuel has to be consumed to generate the same amount of heat.

Burner parameters
There are many variables that can be changed within the burner in order to solve these problems.

- Burner ports
- Burner port configuration
- Burner throat

Burner ports
The size and position of the burner ports are one of the easiest parameters to adjust within the burner. According to the rice husk gas stove handbook (Belonio, A. T. 2005) optimal dimensions for the holes of a rice husk gasifier are 4,7 mm to 6,3 mm with a space of about 3,2 mm. Because there is not similar research on wood pellet gasifier burners this will be used as a starting point for the new gasifier design. The effect of increasing the port size diameter is that the flame speed is decreased, which reduced the tendency of the flames to lift. However, the drawback of a larger port size is that for the same heat power input, there is a reduction of the specific power meaning that the flame is less focused and less hot (Gattei, 2008).

Besides the diameter the shape of the holes can also be adjusted in order to improve the stability of the flame. There are some guidelines available for designing a biogas burner (Fulford, 1996). These are focused to increase the performance by preventing three issues from happening: Flame lift, lighting back and incomplete combustion.

Flame lift

When a flame lifts of the burner port it has a high chance of going out. This effect occurs when the speed of the gas/air mixture through the burner port is higher than the speed of the flame burning in the gas.

According to research the laminar flame speed of producer gas from biomass gasification is less than that of gasoline but higher than greater than that of methane (Hernandez, Lapuerta, Serrano & Melgar, 2005). The laminar flame speed of the gas increases with temperature and decreases with pressure and a higher moisture content in the fuel. The image G.1.2 on the right shows the laminar flame speed at different temperatures with relative gas/ air ratio (Fr). This would indicate that the gas coming from the burner port should not exceed the 0,3 -0.5 m/s. However, in practice the lame speed is not only laminar but also turbulent. With *laminar flow* the gas follows a smooth path, which never interferes with one another and the velocity is constant. With *turbulent flow* the gas is irregular and is not constant at every point which results in a higher flame speed as more oxygen is allowed to be in between the gas particles. For methane the laminar flow is about 0.8 m/s, but when the flame is turbulent it can rise up to 12.8 m/s and can in some extreme cases be as high as 80 m/s. (Sattar, Andrews, Phylaktou & Gibbs, 2014). Besides the turbulence of the flame the temperature, air/fuel mixture (equivalence ratio) and pressure also influence the propagation speed of the flame. By experimenting with different burner setups and air ratios a constant improvement of the burner will be achieved.

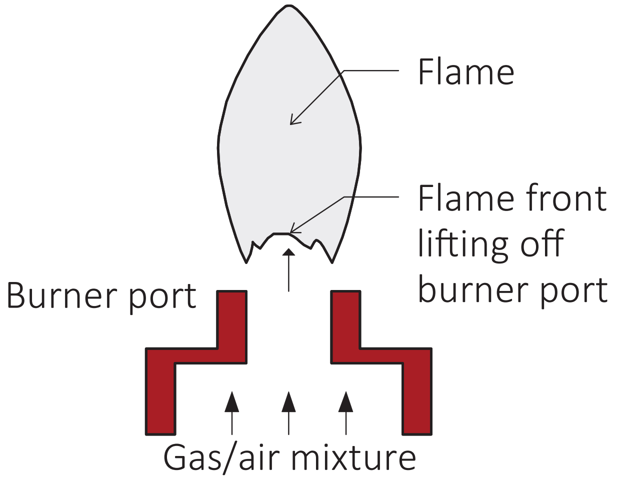


Image G.1.1: Illustration of flame lift from a burner port

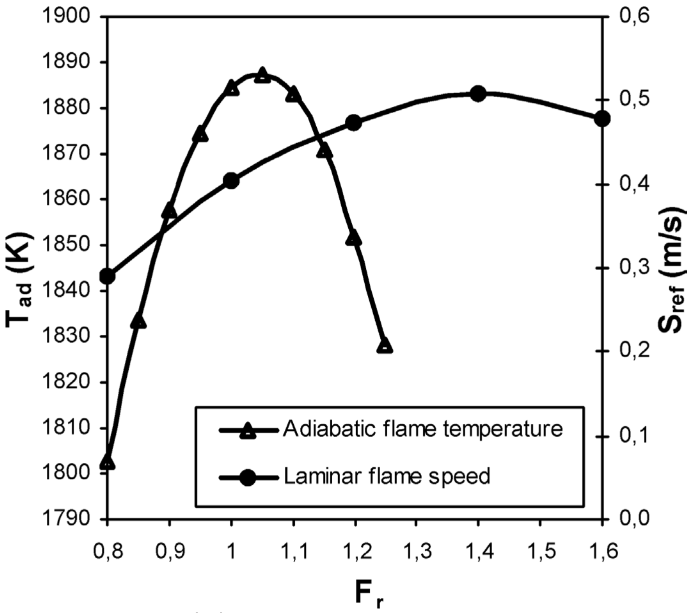


Image G.1.2: (Δ)Producer gas adiabatic flame temperature (T_{ad}) and (●) laminar flame speed (S_{ref}) versus F_r.

Lighting back

What can be observed in the current 2015 prototype of the gasifier is that the produced gas is not burning on top of the gasifier but inside. Reason for this is that the velocity of the gas is lower than the flame speed burning the gas. One way of solving this issues is to increase the speed by reducing the size of the throat. This will require for the burner to slow down the flame to a speed that is low enough for the gas to burn outside at different turn down ratios.

Flame stabilization

Flame stability is an important factor when it comes to cooking. As a result of an instable burner the flame might extinguish which results in harmful gases emitted in the air of people their cooking environment. Especially in unventilated spaces this poses a big danger. In figure G.1.5 on the right there are four different methods to increase flame stability. The first three are focused on allowing more environmental air to reach the bottom of the flame.

A second option is to use retention flames; these are small flames around the main flame. The velocity of the smaller flames is reduced which makes them more stable. In some designs the retention flames create a vortex which also mix the gases in the flame even further. The results in a better combustion and also in a more concentrated flame which are all beneficial for the efficiency.

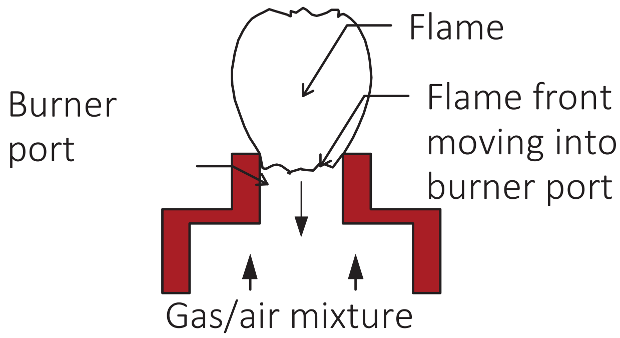


Image G.1.4: Illustration of a flame lighting back in the burner port

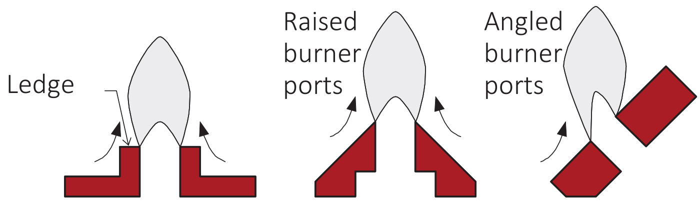


Image G.1.5: Illustration of flame stabilization by increasing environmental (tertiary) air flow

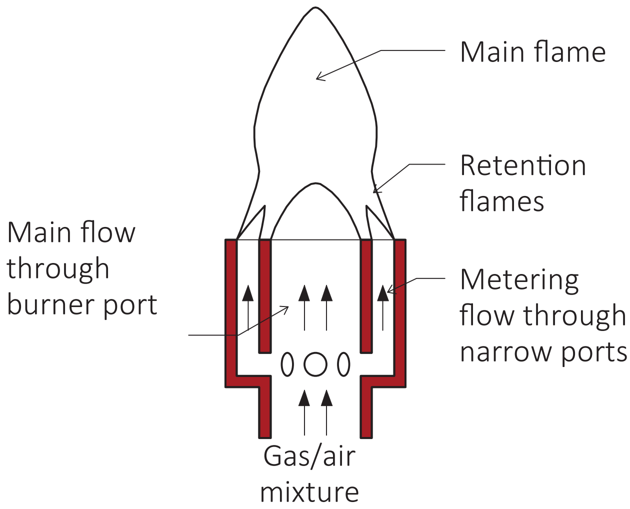


Image G.1.6: Illustration of flame stabilization using retention flames

Image G.1.7: Example of a sheet metal retention burner

A third way to stabilize the flames are the use of eddies. This is a way of flame stabilization by sudden enlargements in the burner ports which results in a drop in velocity. This is often used to burners for closed combustion such as nozzle mixing type burners with sealed in refractory.

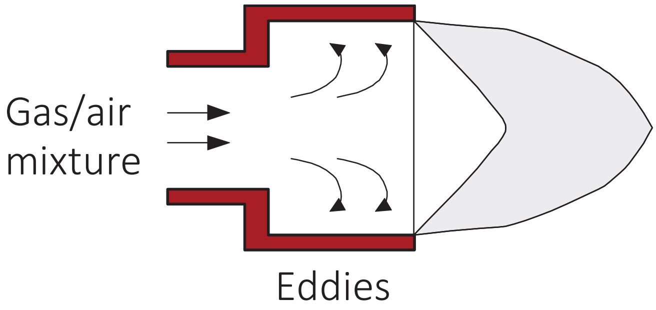


Image G.1.8: Illustration of flame stabilization using eddies

Burner port arrangement

Besides the size and design of the individual port, the location and arrangement is also important. These can be defined by multiple factors such as the heat pattern requirement and the ports to be close enough together for *cross-lighting* of the flames. The latter is the effect of a flame jumping from port to port which helps the user lighting the gas. Another influence the pattern has, is the amount of tertiary air that is able to reach the flames. Looking at figure G.1.9 below, the left shows a pattern where air can barely reach the burning flames. By alternating the holes in the configuration it is much easier for tertiary air to reach the inner burner holes.

Besides functionality aspects of the configuration a burner can also add to the aesthetics by playing with the shape (figure G.1.10).

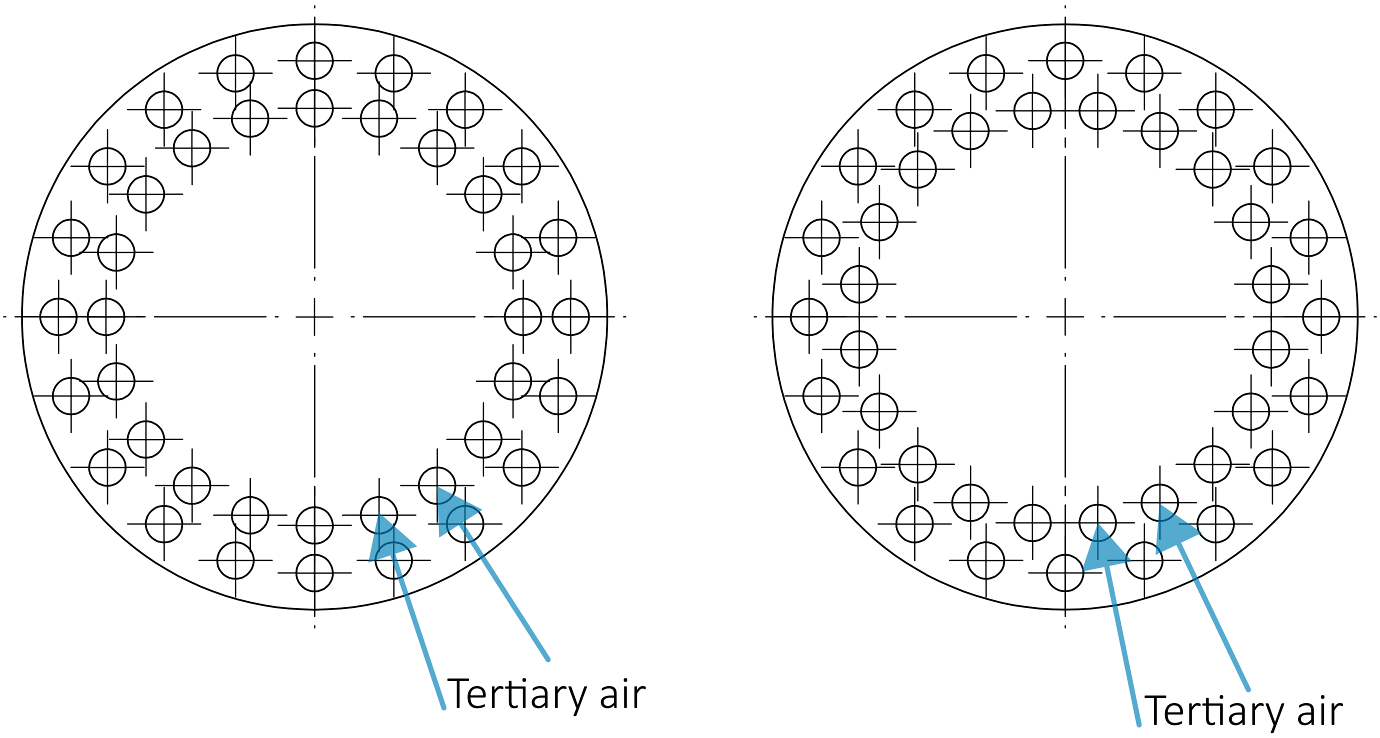


Image G.1.9: Two types of burner arrangements.

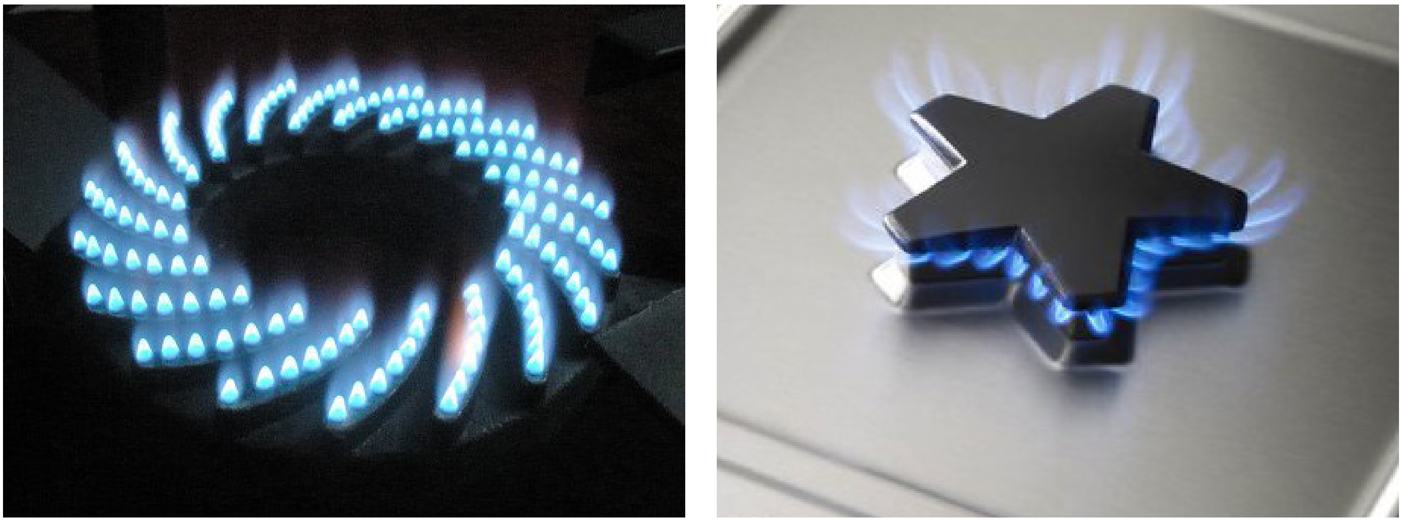


Image G.1.10: Examples of aesthetically shaped burner designs.

APPENDIX G.2: BURNER DESIGN

Concept 1

The theory presented in appendix G.1 will now be applied in a new design concept. Following the 'lean' methodology improvements will be made after each prototype. In this first concept three principle will be tested: Mixing of the primary and secondary air, using a funnel to increase usability and burner port configuration (image G.2.1).

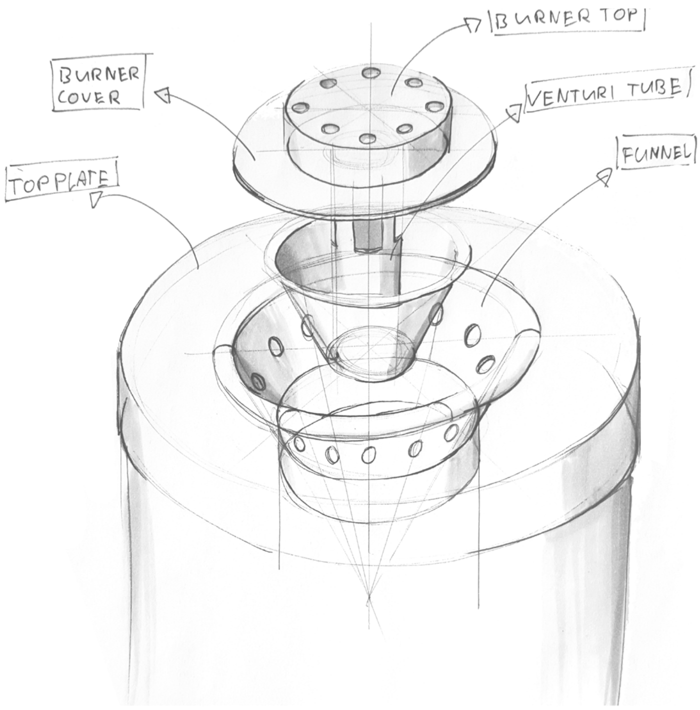


Image G.2.1: Schematic drawing to the burner concept

Venturi tube

One way of mixing the primary and secondary air flow is with the venturi effect. This effect uses a tube with a relative small diameter to accelerate the primary gas flow. According to Bernoulli's principle an increase in the speed of gas occurs simultaneously with a decrease in pressure. By making holes in the side of the tube allows secondary air to get suck in to the tube due to the negative pressure. After the gas is mixed inside the tube, it has to slow down in the burner top by the increase in volume.

Funnel

Looking at the sketch one other component is added, compared to the CCS prototype. A funnel is placed between the reactor and the inner cylinder. Instead of having an open space at the top a funnel such as this would have the following advantages:

- Easier filling of the fuel
- Can be used as advanced cookstove without the burner
- Suitable for more types of fuel
- Guidance of the reactor in the gasifier

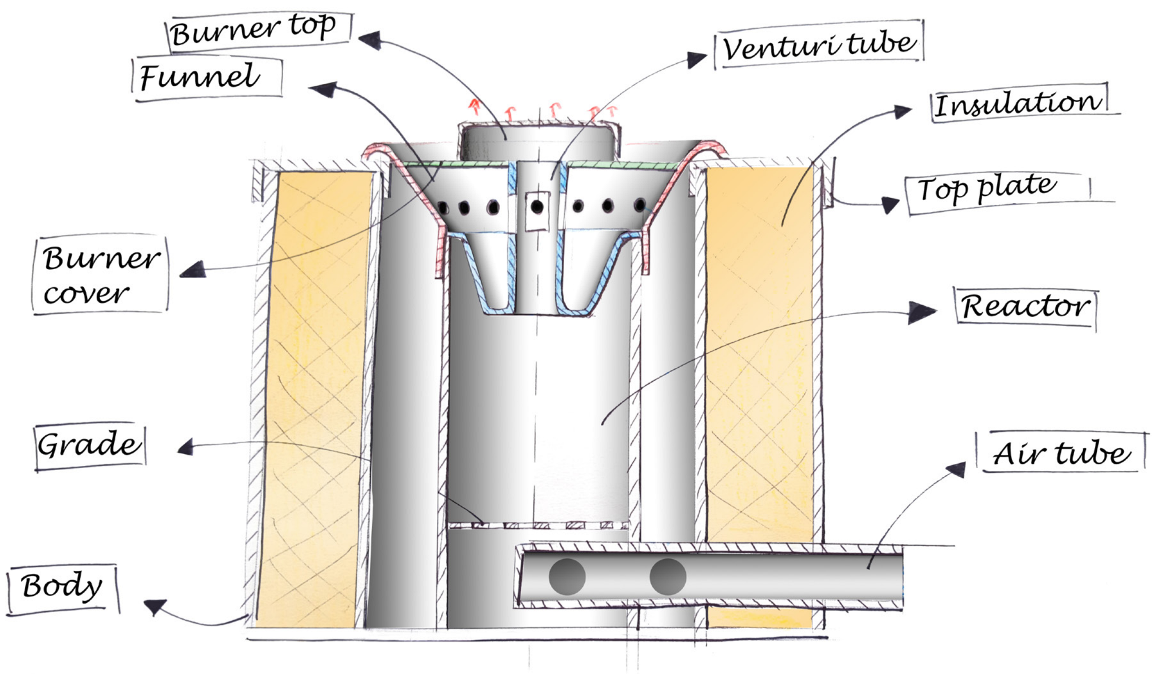


Image G.2.2: Cross section drawing of the burner concept

Burner 1 flow simulation

Airflow

Before the prototype is made an airflow analysis in SolidWorks flow simulation is modeled. This simulation is to estimate the velocity of the gas inside the venturi tube and when the gas leaves the burner ports. The flow trajectories are plotted to show how the gas behaves inside the gasifier. The centrifugal fan of the SolidWorks library is adjusted to meet the specifications of the CCS gasifier fan presented in appendix D.2.

Velocity

As shown in image G.2.4 on the right there is a large increase in the velocity when the gas goes through the venturi tube (diameter of 15 mm). The cut plot shows a maximum velocity of 15.5 m/s. As explained it is important that the gas should not be able to burn inside the burner, taking into account that this speed is much higher than the laminar flame speed with little turbulence in the straight pipe it should go through without burning. On top when the gas exits the burner ports the velocity is reduced to almost 2 m/s.

Flow trajectory

Looking at the flow path of the gas it can be observed that a lot of turbulence is created, the advantage of this is that it enhances the mixing the primary and secondary air which results in a cleaner combustion. Tests should determine if this configuration has the desired effects.

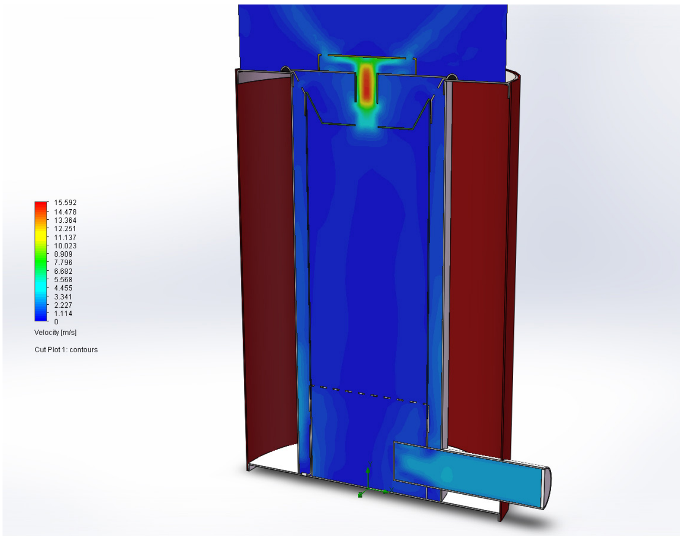


Image G.2.3: Cut plot of gas velocity in SolidWorks

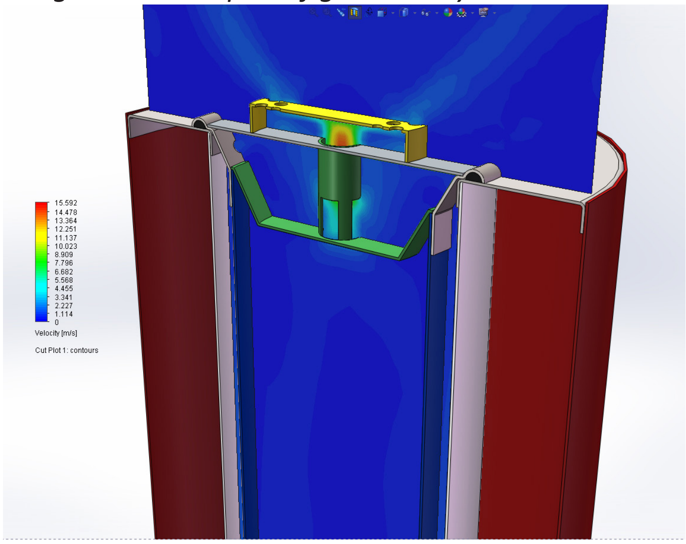


Image G.2.4: Cut plot of gas velocity in SolidWorks with a cut view 10 mm from the center

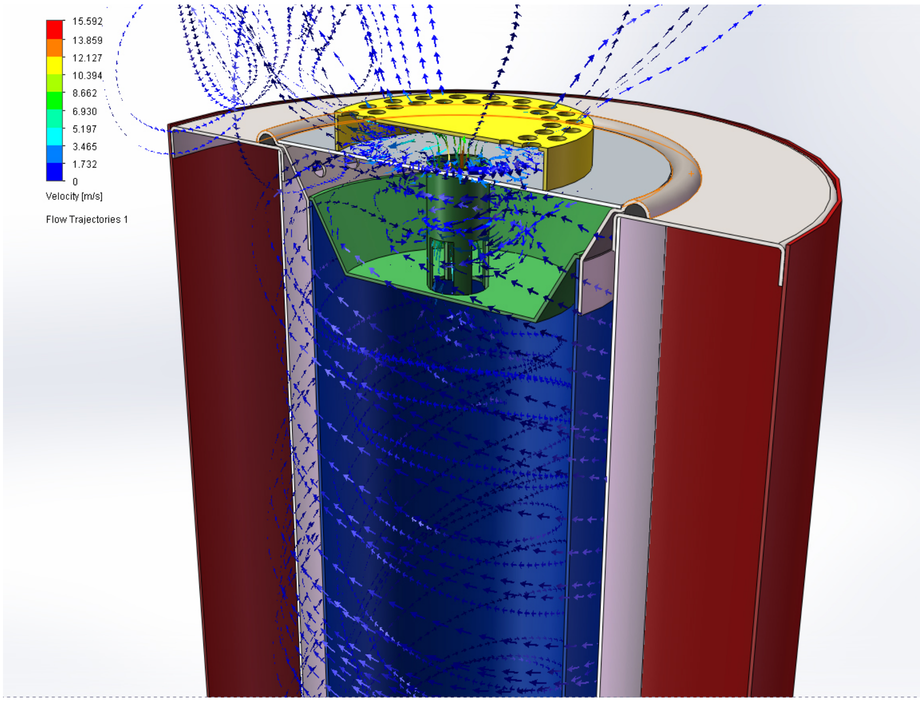


Image G.2.5: Flow trajectory of the air at the top

Burner 1 prototyping

Most parts of the prototype are manufactured using spin forming. First a blank is fabricated from mild steel according to the technical drawings provided (appendix H.6). Image G.2.7 on the rights shows one of the blanks made for the funnel. The blank is then placed in the turning table and a roller tool pushes the sheet metal over the blank. An illustration of this process is shown in image G.2.6 on the right.

Challenging in this process are sharp corners and should be avoided or the metal might shear. Especially for stainless steel as this has a higher stiffness compared to plain mild steel.

Looking at image G.2.8 (1) and G.2.9 (1) the funnel and the burner top plate it can be noted that they have a bead pressed into them. This is to avoid transformation of the part caused by the heat during operation.

To account for any tolerance the venturi tube is made a little longer with the tube being slightly thinner at the top so it fits the hole in the bottom of the burner top plate image G.2.10 (2).

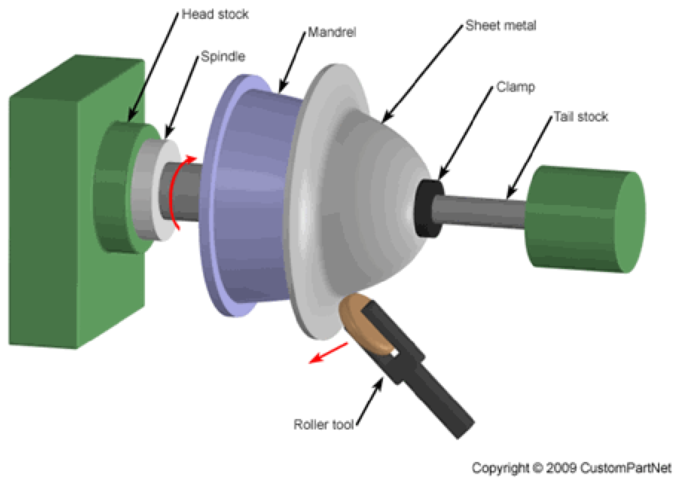


Image G.2.6: Spinning manufacturing process

Image G.2.7: Blank of the funnel

Image G.2.8: The funnel with holes drilled on the side

Image G.2.9: Top view of the burner top with two circular patterns rows 20 holes

Image G.2.10: Burner cover with venturi tube

Image G.2.11: Bottom view of the burner top

Burner 1 testing

Both the reactor and the funnel are properly closed off allowing no uncontrolled oxygen to enter the process.

Image G.2.12: Placement of the burner cap with venturi tube

Image G.2.13: Placement of the burner on top of the gasifier

Image G.2.14 shows how the reactor can be placed inside the stove using a special tool and the guidance of the funnel. Unfortunately, it appeared that it was difficult to slide the reactor in and the funnel did not provide much guidance.

Image G.2.14: Placement of the reactor through the funnel

Image G.2.15 (3) on the right shows the working principle of the venturi tube. It appears that the diameter of the tube in correctly chosen as the gas is not burning inside the tube. As soon as the gas leaves the tube more oxygen is added from the environment and the velocity is reduced at which point the gas can burn.

Image G.2.15: Venturi tube accelerating the gas during operation

Testing the stove revealed interesting results. The burner did not manage to make the flame burn on top and heated the burner red hot. It is assumed this is caused by the high turbulence created in the burner top and a wrong equivalence ratio. Too much secondary air added. The flame without the burning using just the funnel showed promising results. The flame was very stable and a vortex created in the center concentrating the heat. This shows promising results when the gasifier would be used for other types of non-pelletized biomass fuels.

Image G.2.16: Burner placed on top getting red hot

Image G.2.17: Gasifier in operation without the burner on top, creating a vortex flame

Burner 2 design

Looking at the results from the previous gasifier an effort was made to reduce the turbulence inside the burner. Besides the flow of the gas the usability is also tried to be improved.

Usability

By reducing the handling of having to place two separate burner parts on top, to only one step. Image G.2.18 on the rights shows the three parts of the burner which can be assembled as one burner. Image G.2.20 shows the cross section of the burner placed in the gasifier. The bottom part (red) should close of the reactor allowing only the primary air going through the center. At this point, the gas will accelerate and mix with the secondary air that comes from the funnel holes. Image G.2.20 also shows a second option for this configuration, instead of a flat burner surface the holes are now arranged on an incline surface. This should concentrate the flame to the center and could also help priming other flames when they blow off.

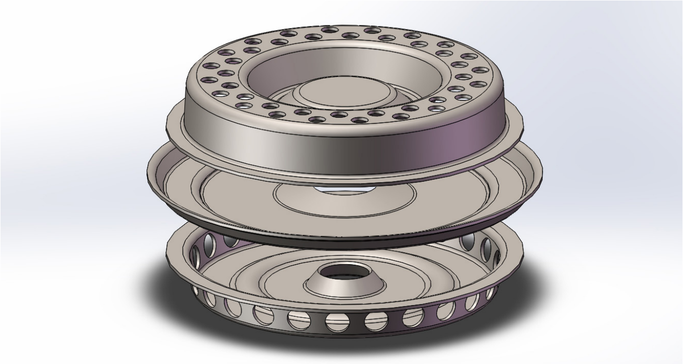


Image G.2.18: Assembly of the three burner parts

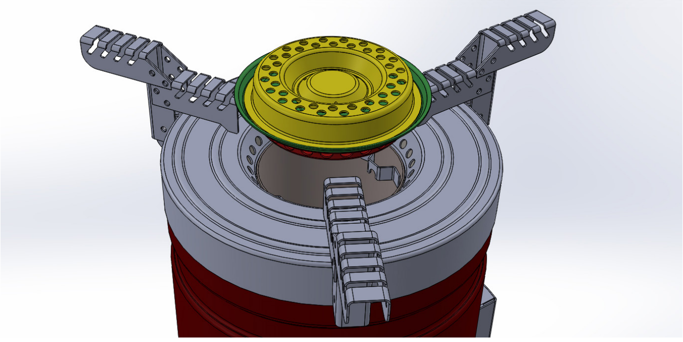
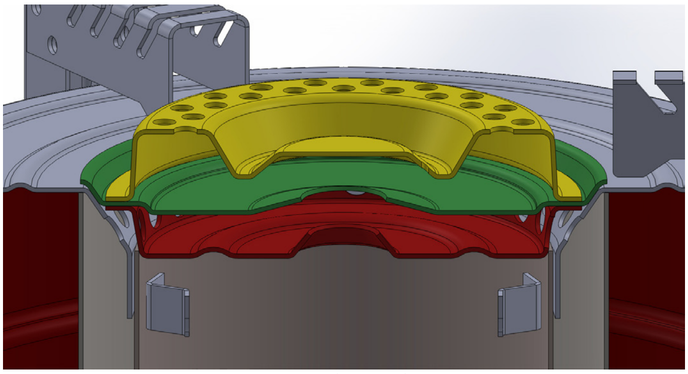


Image G.2.19: Placement of the burner in the gasifier



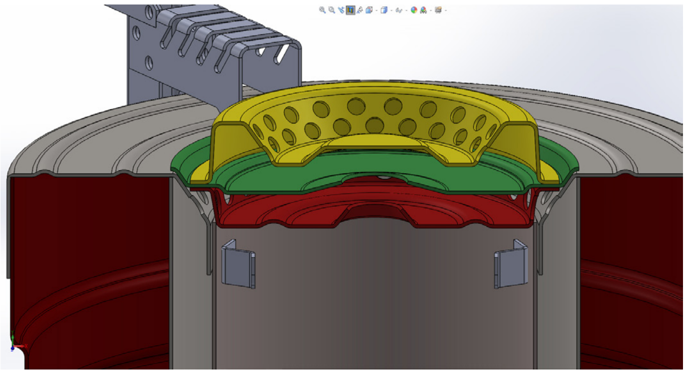


Image G.2.20: Cut view of the flat burner and the incline burner

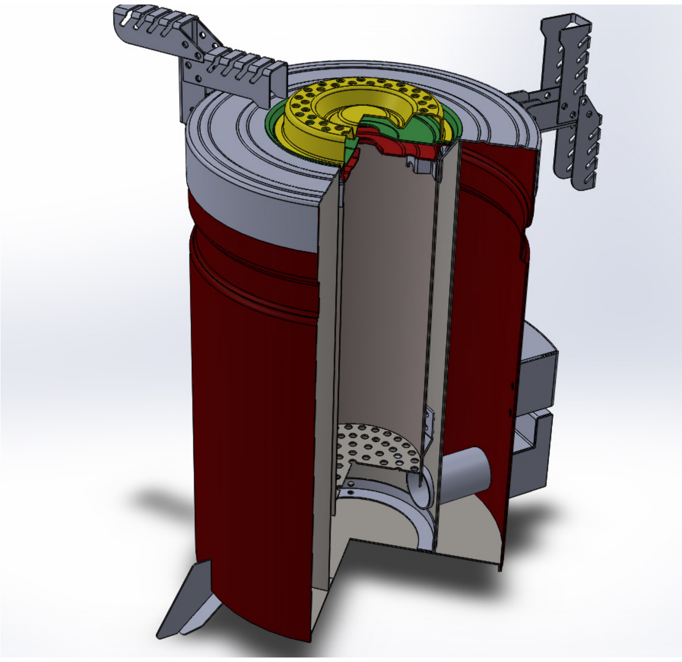


Image G.2.21: Cut view of the gasifier with burner

Design

The funnel is now integrated within the top plate, this should improve the placement of the reactor tube. The issue with the funnel being a separate part is that it does not provide stable support and tends to move when placing the reactor. The top plate should also be placed over the outer body to avoid dust or food particles to get stuck in the edge. A first idea is also presented of a collapsible pot support and sheet metal feet which will be further elaborated in appendix G.2.

Burner 2 flow simulation

Flame stabilization burner

The new burner design should increase the flame stabilization. By allowing the flow of the gas move through a more guided path, the gas should flow more laminar, thereby decreasing the flame speed as a cause of turbulence. In the old burner design the gas would hit onto the flat top surface perpendicular. The new designs have a curvature at the top, which forces the gas the outside of the burner (image G.2.22). Besides the shape, the volume of the burner also increased to give the gas more space to slow down but keeping a constant pressure. Comparing the velocity of the air to the old simulation results there are some differences:

- The maximum velocity obtained in the center is 11.14 m/s for the new design and 15.5 m/s for the old design. This difference can be explained by the fact that the tube is removed so the gas has less length to accelerate.
- The speed of the air that exits the burner ports is 1.5 m/s for the new design compared to almost 3 m/s in the old one. This is both due to the increase in volume and the decrease in acceleration of the gas by the narrow center holes.

Reactor placement

For the airflow at the bottom the possibility is investigated to eliminate the bottom cylinder in which the reactor is placed. This is replaced by three clamps which also support the placement of the reactor. The ratio between the primary and secondary is should now be divided by the size and number of holes in the funnel.

Flow trajectory bottom

Looking at the trajectory plot from the simulation most of the air goes straight through the gasifier as secondary air. This makes it hard to build up pressure for the primary air which is desirable for a constant movement of the MPF (chapter 4.1.3). Other ways of dividing the two air flows with the same advantages for usability should be further investigated. For now nothing is changed to the bottom and the airflow division is kept the same.

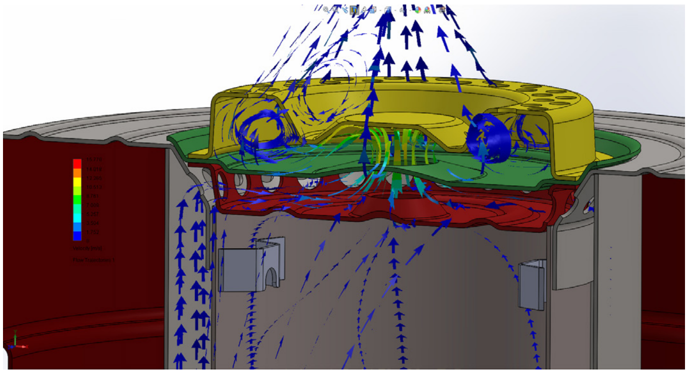


Image G.2.22: Flow trajectory of the air in the burner

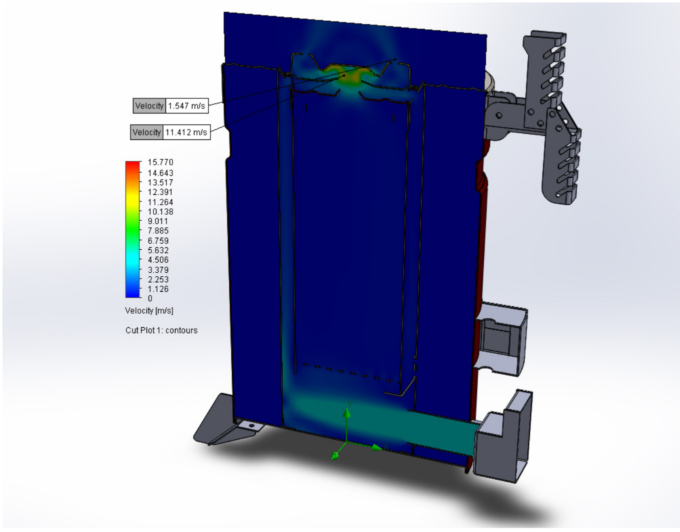


Image G.2.23: Cut plot of the air velocity in the gasifier

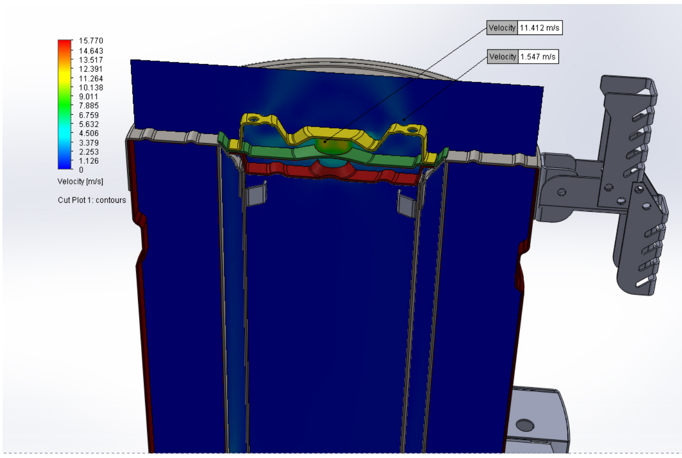


Image G.2.24: Cut plot of the air velocity in the burner

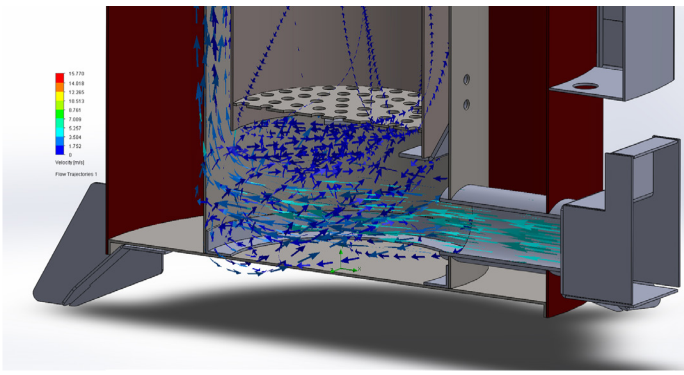


Image G.2.25: Flow trajectory at the air tube in the bottom

Burner 2 prototype

For the fabrication of this burner the same manufacturing techniques are used as the previous prototype. It is chosen to use the same blank for the burner with the holes arranged in an incline position as the one with the flat top burner holes. Because the burner is now build up from one three parts it makes it much more robust than the previous burner prototype.

Figure G.2.28 and G.2.29 show both burners placed on top of the gasifier and appear to be fitting well. It is important that the reactor is properly sealed of so the produce gas only flow through the center hole where it accelerates.

Technical drawings of this design can be found in appendix H6.

Image G.2.26: Top view of the two prototype burners

Image G.2.27: Bottom view of the two prototype burners

Image G.2.28: Incline burner placed on the gasifier

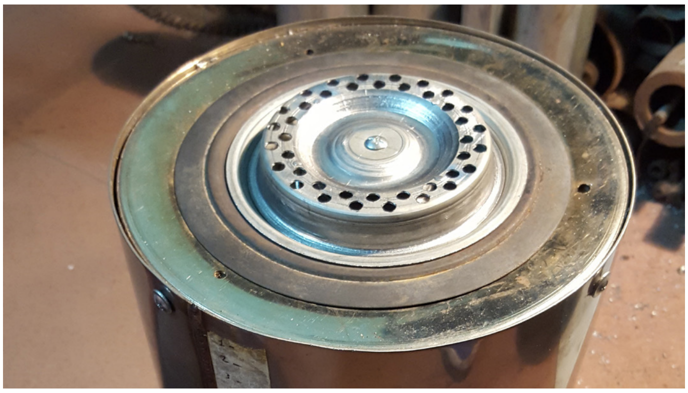


Image G.2.29: Flat burner placed on the gasifier

Burner 2 testing

Incline burner

Tests is executed in order to determine the performance of these two burner. Image G.2.29 on the right shows the flame of the incline burner. The following positive and negative points can be taken away from initial testing:

Positive

- Flame appears to have a clean combustion as there is no yellow flame or smell.
- The flame gets concentrated in the center which might be beneficial for smaller pots.
- Placement of the burner is easy with a long plier, though some special tool or attachment should be designed for the user to place it safely without getting burned.

Negative

- The flame does not appear to be powerful which might be due to the high turbulence inside the burner which disturbs the airflow.
- Flame is burning inside the burner, which heats the metal red hot creating a loss in thermal efficiency.
- The reactor might not be completely sealed off, which causes the produced gas to mix in a low velocity zone instead of in the center.
- When the produce gas is mixed inside with low velocity it will start the combustion reaction inside the burner.

Flat burner

The flat top burner shows a clear distinction in the flames coming from the burner holes, with similar characteristics of a LPG-gas flame. The following positive and negative points can be taken away from initial testing:

Positive

- Flames have a better flow through the burner ports which results in less turbulence.
- Flame appears to have a clean combustion as there is no yellow flame or smell.
- The gasifier has a good turn-down ratio for high an low power modes.
- The size of the flame is good for big and smaller pots.

Negative

- The reactor might not be completely sealed off, which causes the produced gas to mix in a low velocity zone instead of in the center.

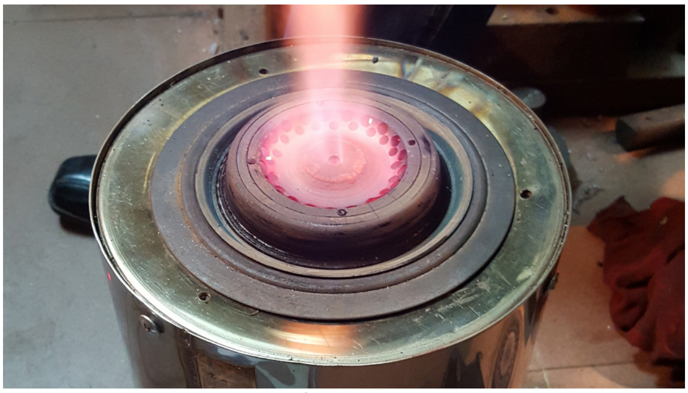


Image G.2.29: Flame of the incline burner during operation

Image G.2.30: Flame of the flat burner during operation

Image G.2.31: Flame of the flat burner during operation

Image G.2.32: Flame of the flat burner in high power mode with a pot placed on top

Burner 3 design

The second burner design was another improvement for the burner, but the main problem still remained as the flame was still burning inside. It is expected that this is partly due to too much secondary air being added within the burner. Too solve this issue and increase the flame stability three parts of the burner were changed:

- Yellow part: This part remains much the same except that some holes at the top are slightly bend upwards. This should increase the flame stability as tertiary air is able too reach the flame at the bottom easier.
- Green part: It is chosen to drill some holes (16 x Ø 3 mm) within the boundary plate. These holes will allow secondary air to go through and mix with the produce gas closer to the burner holes.
- Red part: The seal of the reactor is changed to a thicker separate mild steel part made by spinning in a turning table. This part gets very hot and is subject to most of the heat and gases that are produced. It is assumed that the additional thickness will improve the life span of the burner. A small standard tubing is welded to accelerate the produce gas.

Going back to two separate parts does require the user to have one additional step when placing the burner. However, it is necessary with the current tolerances in our prototyping.

Primary & secondary air flow

For the airflow simulation another idea is tested to divide the airflow without the need for special control valve. Two holes are drilled at the side of the tube which should produce the main flow for the secondary air. Another larger hole at the top is aimed directly at the fuel which should produce most of the primary air.

- The maximum velocity obtained in the center is 11.14 m/s for the new design and 15.5 m/s for the old design. This difference can be explained by the fact that the tube is removed so the gas has less length to accelerate.
- The speed of the air that exits the burner ports is 1.5 m/s for the new design compared to almost 3 m/s in the old one. This is both due to the increase in volume and the decrease in acceleration of the gas by the narrow center holes.

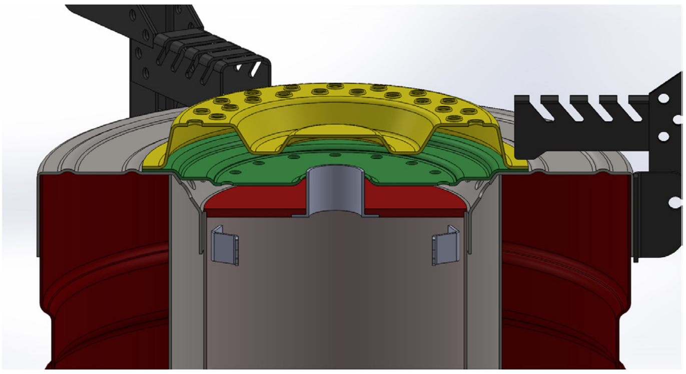


Image G.2.33: Cut view of burner 3 in SolidWorks

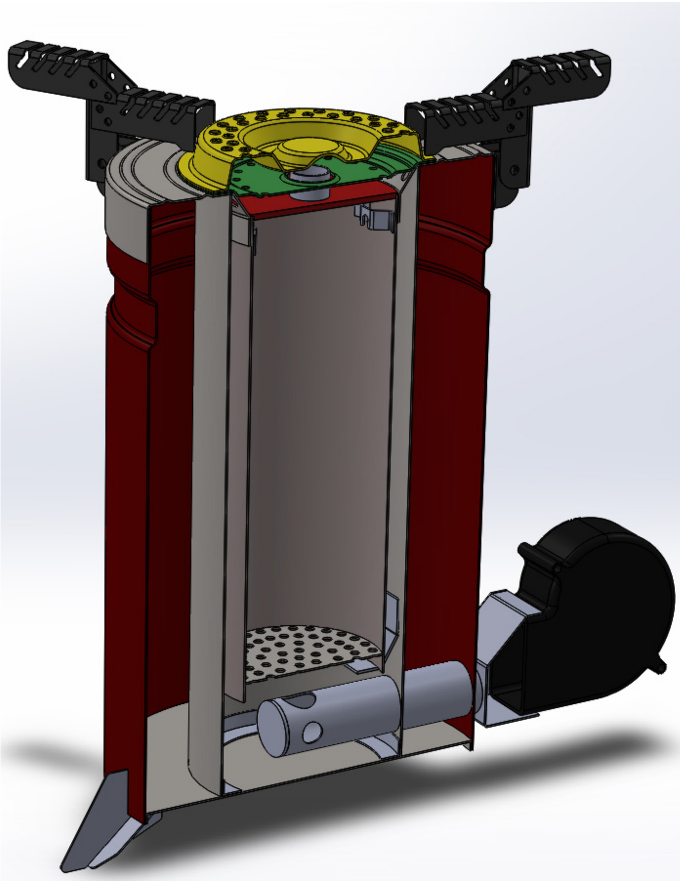


Image G.2.34: Cut view of the total gasifier with new burner and air division tube

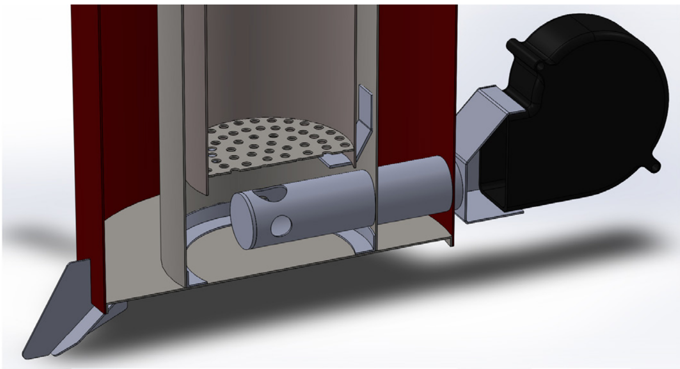


Image G.2.35: Close-up of the air division tube

Burner 3 flow simulation

Image G.3.26 and G.3.27 show a cut plot of the air velocity in the burner. Within the tube (Ø 14 mm) the velocity is accelerated to 8.5 m/s. This is much lower than the previous simulation and can be explained by the way how the secondary air is mixed. Instead of mixing the produce gas with the additional secondary air in the tube they are now mixed in the burner top; hence less volumetric air has to go through the narrow space.

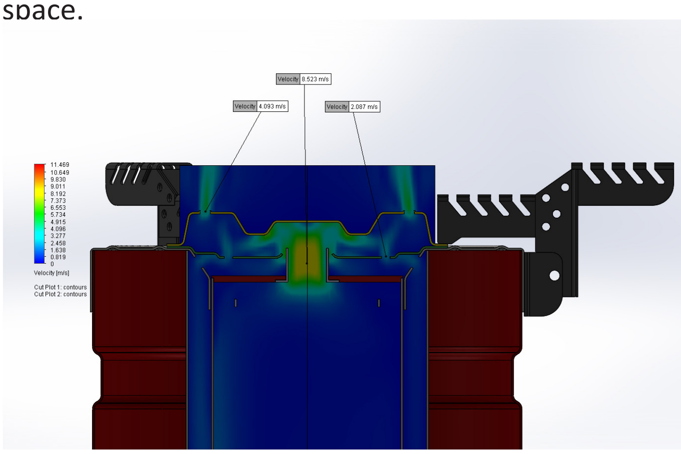


Image G.2.36: Front view cut plot projecting the air velocity in the burner

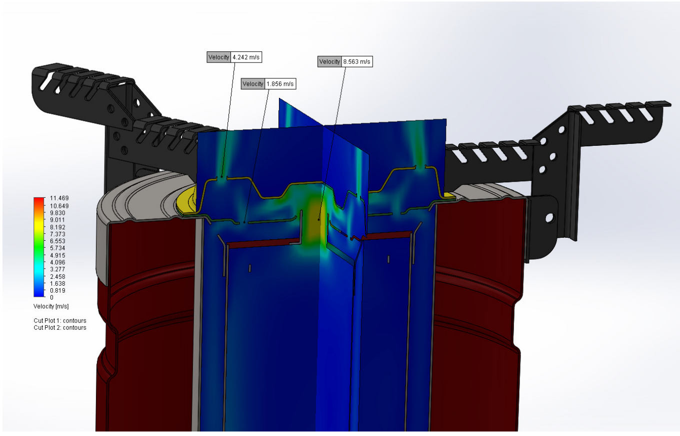


Image G.2.37: Three dimensional view of the cut plots projecting the air velocity in the burner

Image G.3.38 and G.3.39 show the cut plot of the air velocity at the bottom. The primary air is jetted towards the fuel grade and hits the bottom slightly off the center. Therefore the tube should be shorter, so the primary air is divided more evenly across the surface.

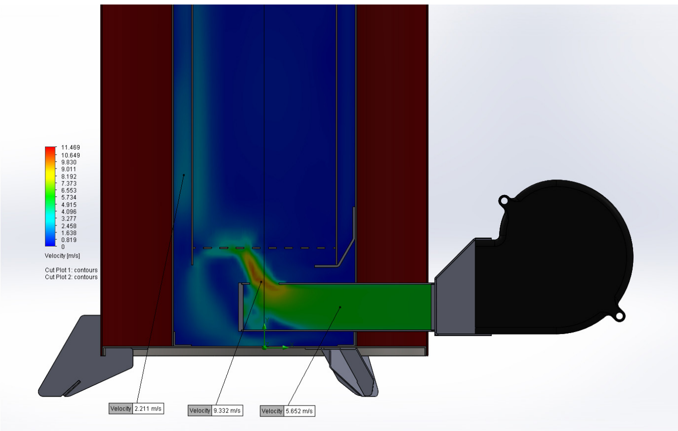


Image G.2.38: Front view cut plot projecting the velocity in the air tube

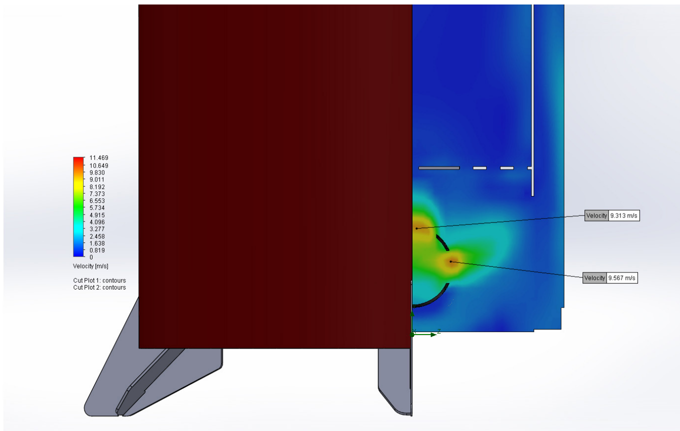


Image G.2.39: side view cut plot projecting the velocity in the air tube

The flow trajectory at the top shows a good distribution of the air in the burner. It is also important that the turbulence occurred in the previous burner was reduced, which appears to be the case in this version. Looking at the flow in the air tube in the bottom, it can be observed that the grade has a some resistance on the air flow. A test should determine if this way of air division could work in practice.

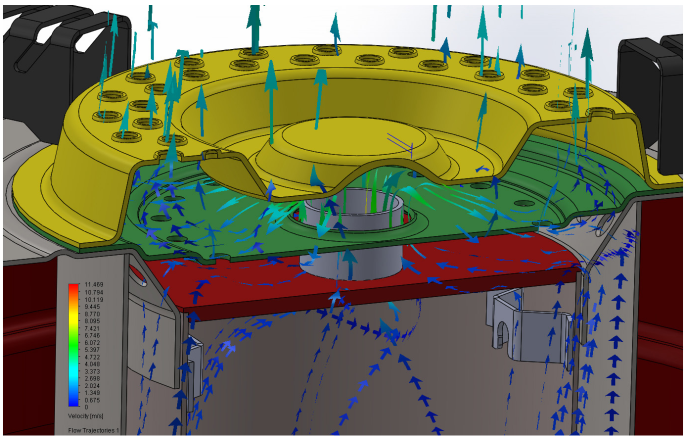
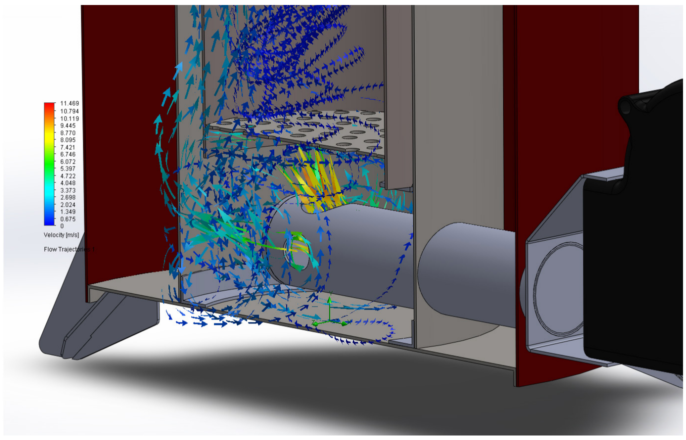


Image G.2.40: Flow trajectory in the burner



ImageG.2.41: Flow trajectory in the air tube

Burner 3 prototype

Image G.4.42 on the right shows the new prototype of the burner cap. A standardized tube was cut to length and welded to the disk

As a suggestion from the workshop a disk was added to the boundary plate. The purpose of this disk is to be able to change the amount of holes and the position for the secondary air to go through. It can then be tested if the position where the secondary air meats the produce gas has any influence on the quality. The gas is best mixed with the secondary air when it is bounced from the top perpendicular to the holes where the secondary air flow through.

Image G.2.42: Reactor cap with tube

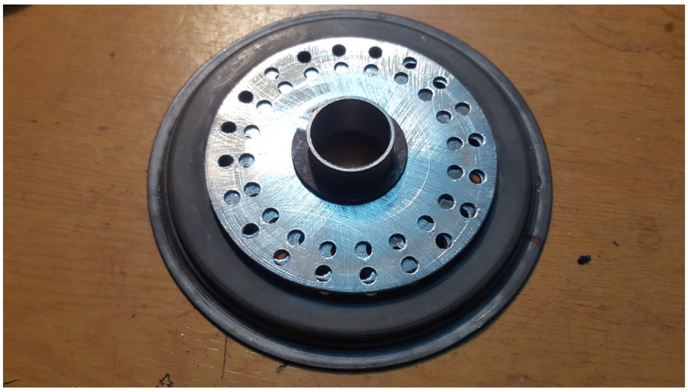


Image G.2.43 & G.2.44: Boundary plates showing different positions of the added ring to adjust the airflow of the secondary air.

Looking at the top of the burner in image G.4.45, the holes can be seen with the bended edges. It can also be observed that there are three holes drilled in the center. These holes should allow gas to flow through and prime the flames in the outer ring.

Too improve the placement of the burner during the operation a screw is placed in through the center. A plier can safely grab the burner even during usage.

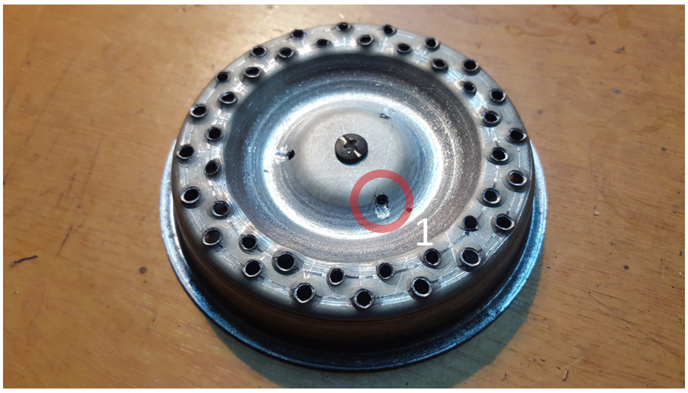


Image G.2.45: Improved burner top with center primer holes

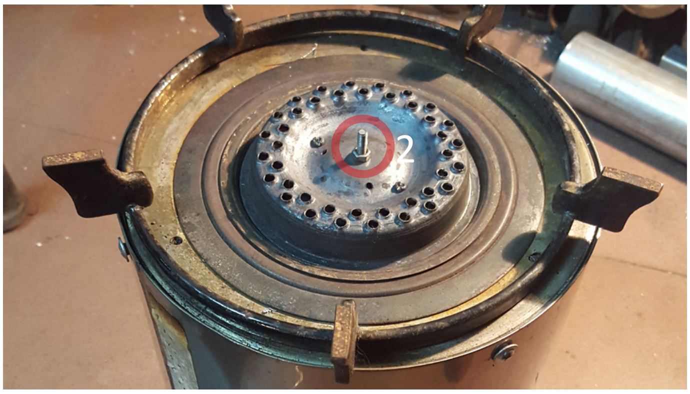


Image G.2.46: Burner placed on the gasifier

Burner 3 testing

Image G.2.47 on the right shows the working principle of the new reactor cab. The gas is greatly accelerated causing it to move faster than the flame speed just when it leaves the tube, when the distance is increased and the gas is slowed down it will burn.

Image G.4.48 and G.4.49 show the gasifier with the burner placed on top. Within this test some good results were obtained. The gas is finally burning completely outside, on the top of the burner ports. During the test the burner top did not reach the high temperatures from the previous versions as it was not glowing red (which happens at temperatures from 525-975 °C for stainless steel). This means that more of the energy from the gas will be used for the cooking task.

Positive

- Flame is burning on top of the burner ports
- Flames have a better flow through the burner ports which results in less turbulence.
- Flame appears to have a clean combustion as there is no yellow flame or smell.
- The gasifier has a good turn-down ratio for high and low power modes.
- The size of the flame is good for big and smaller pots.

Negative

- Might be more sensitive to blow off flames, especially in windy environments.
- Two steps are required from the user to place the burner. First the reactor cap and then the top part.
- After placing the burner, the gas has to be ignited. This means that for a short period, toxic gas is emitted in the air. The same occurs when you would start your LPG cooker except propane gas is less harmful then the gas produced from a gasifier.
- The burner should only be placed when the quality of the produced gas is high enough. This is usually after 10-15 minutes when temperatures are high enough.

Image G.2.47: Reactor cap placed on top of the gasifier during operation

Image G.2.48: Top view of the flame from produced by the third burner design

Image G.2.49: Produced flame burning on top of the burner ports

Image G.2.50: Burner 3 with pot placed on top

Burner 4 design

Another idea was tested decrease the possibility for the flame to burn inside as a cause of too much secondary air and low velocity. It is reasoned that secondary air can also be added outside of the burner entirely. Jetting the produce gas and secondary air perpendicular to each other, will force them to mix and ignite which could increase the efficiency as the combustion reactions is closer to the pot. This means that there is less distance for losing thermal energy. Image G.2.51 on the right shows a schematic of the air flow.

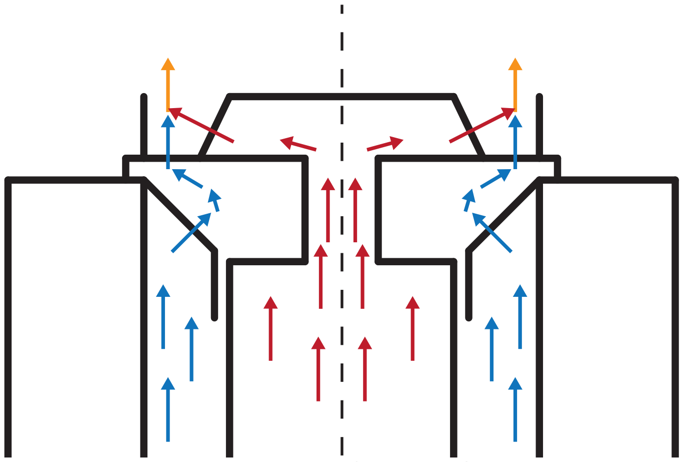


Image G.2.51: Schematic of the air flow in burner 4

Burner 4 prototype

To test this idea another prototype is made using the blanks from previous burners and the burner cap from the third burner prototype. Holes were drilled in the boundary plate and top cap, the ring on the outside should improve the mixing of the two gases and direct the flame up.

Image G.2.52: Bottom view of burner nr. 4

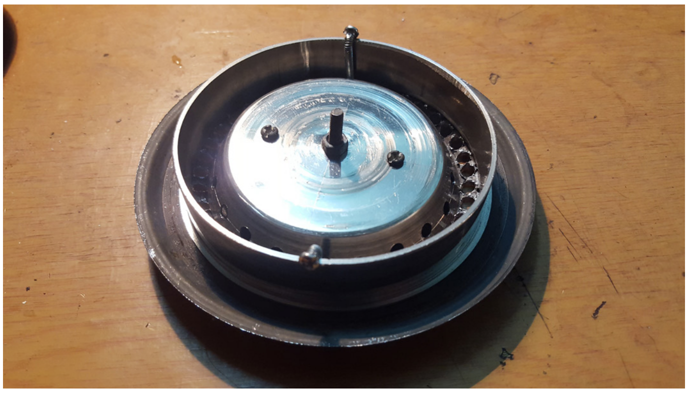


Image G.2.53: Top view of burner nr. 4

Burner 4 testing

Tests of the burner reveal that the flame was not burning completely outside the burner. Besides this the deflection of the flames on the ring caused it to heat up which decreases the thermal efficiency. Especially the results obtained with the burner in the simmer mode (image G.2.55) showed that the flame was burning outside, but most of the heat was directed to the outer ring instead of the bottom of the pot.

Image G.2.54: High power mode of the burner

Image G.2.55: Low power 'simmer' mode

Burner 5 design

Parallel to burner 4 another idea was developed. In order to decrease the amount of parts it was explored to burn the produce gas directly from the reactor and forcing it to mix with the secondary air coming out of the funnel holes. From previous tests it was already known that without a special burner top the flames came from the secondary air holes. The only downside is that the flames should hit the bottom of the pot with some force in order to have a good transmission of the energy in the flames.

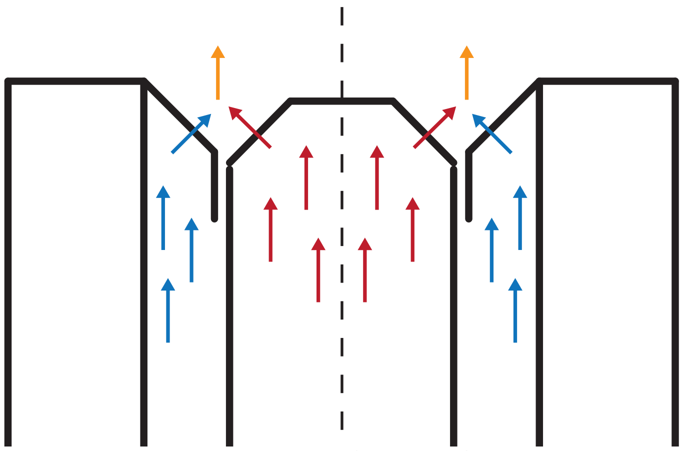


Image G.2.56: Schematic of the air flow in burner 5

Burner 5 prototype

A simple prototype was made to test this setup. Image G.2.57 and G.2.58 show the bottom view of the burner and how it is placed on the gasifier. Old blanks were used in order to produce this part.

Image G.2.57: Bottom of burner nr. 5

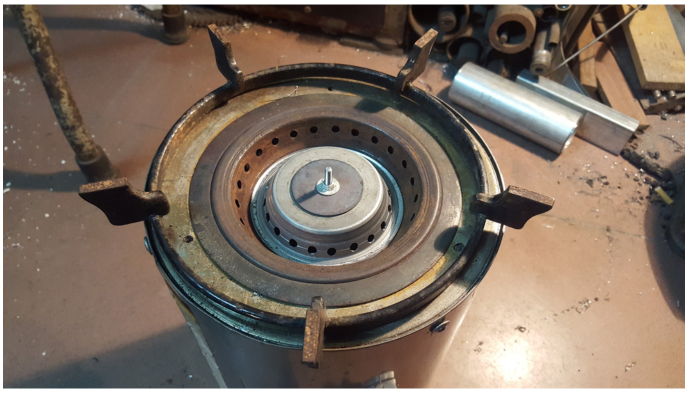


Image G.2.58: Burner nr. 5 placed in the gasifier

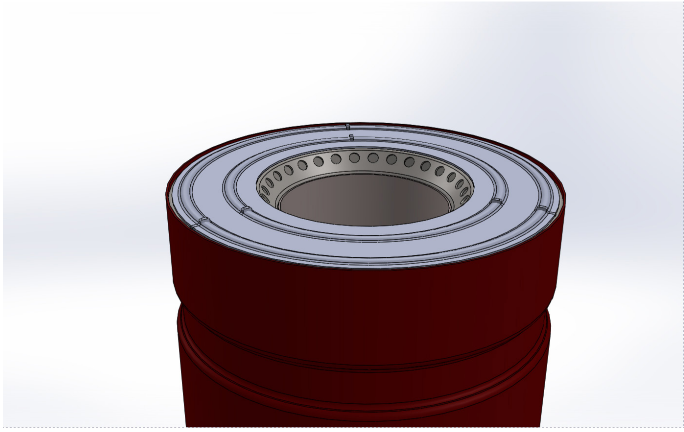
Burner 5 testing

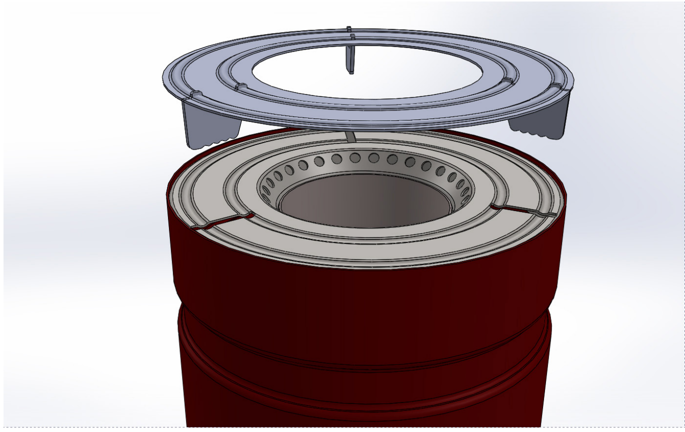
Image G.2.59 shows how the gasifier operates without a burner. The flames get concentrated in the center creating a vortex that mix the gas even further. When the burner is placed on top most of the flames come from the burner ports and only do not mix very well with the secondary air. The flames are also not aimed to the top which makes this burner not an improvement.

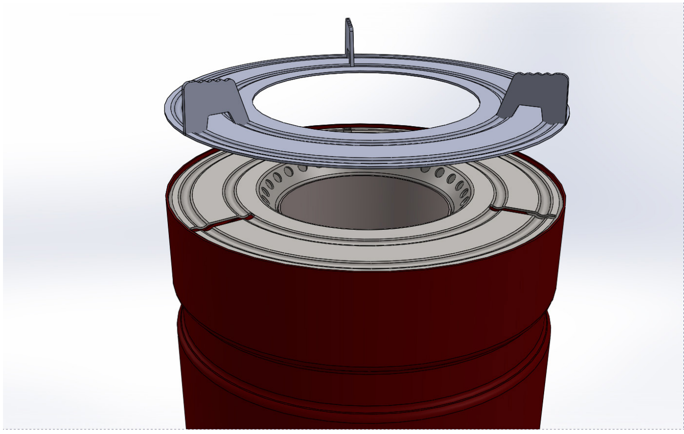
Image G.2.59: Flames coming from the funnel

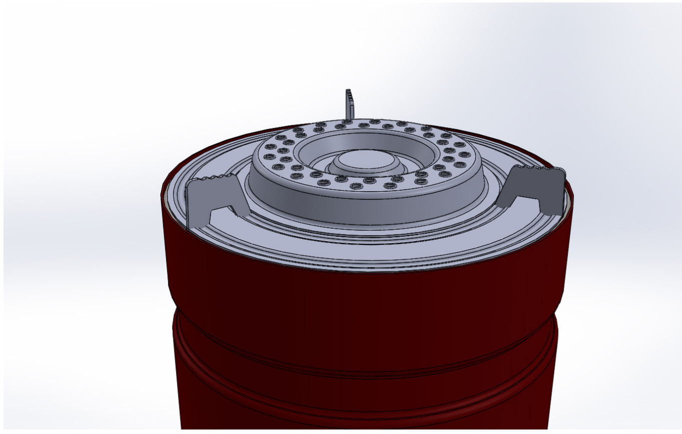
Image G.2.60: Burner placed on top of the reactor

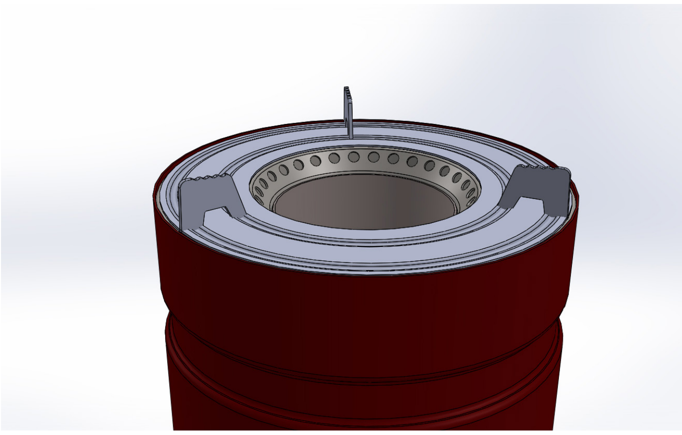
Idea 1 removable plate



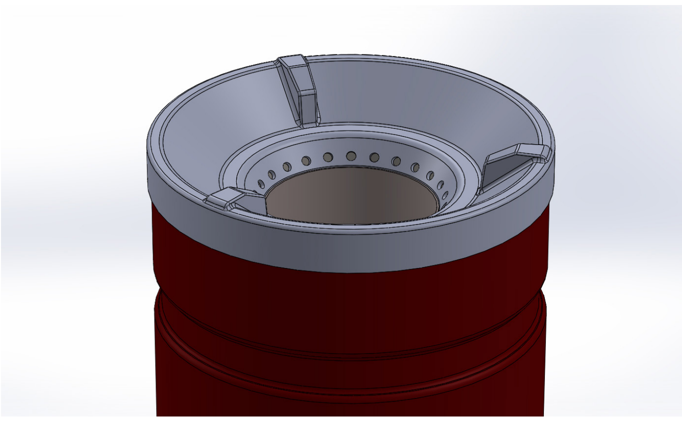


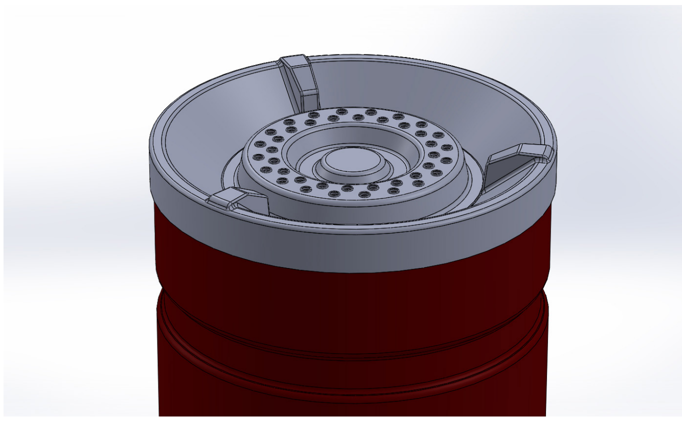




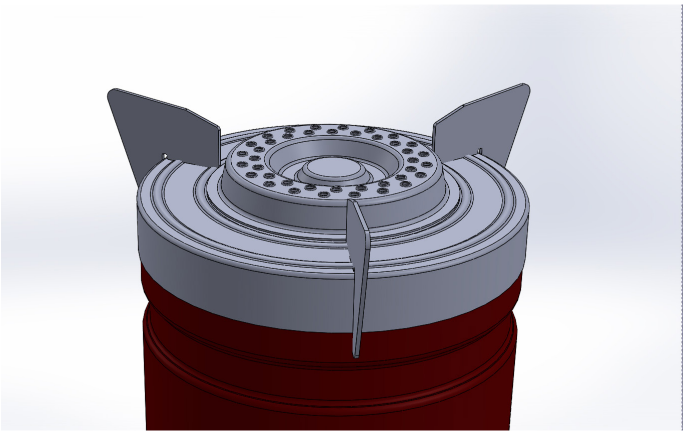


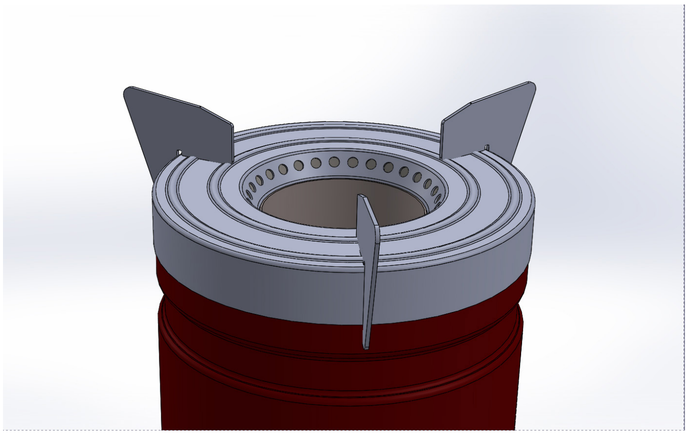
Idea 2 cast iron support



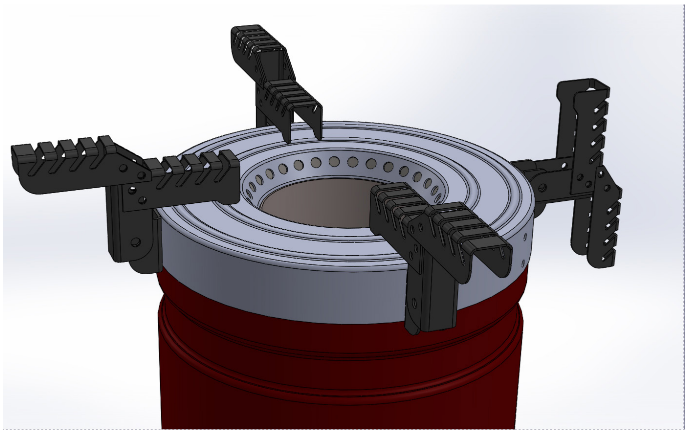


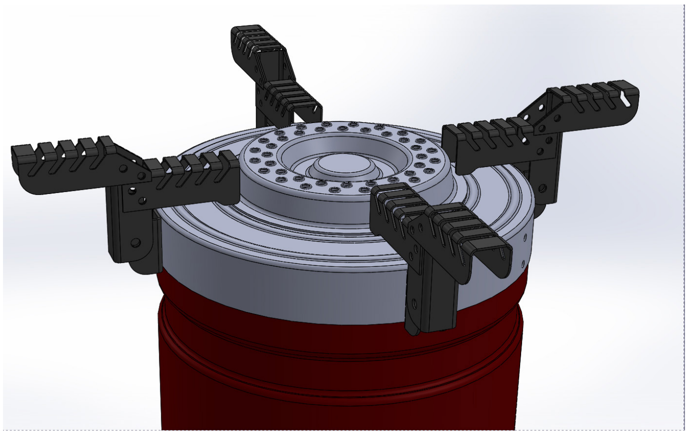
Idea 3 Sheet metal support



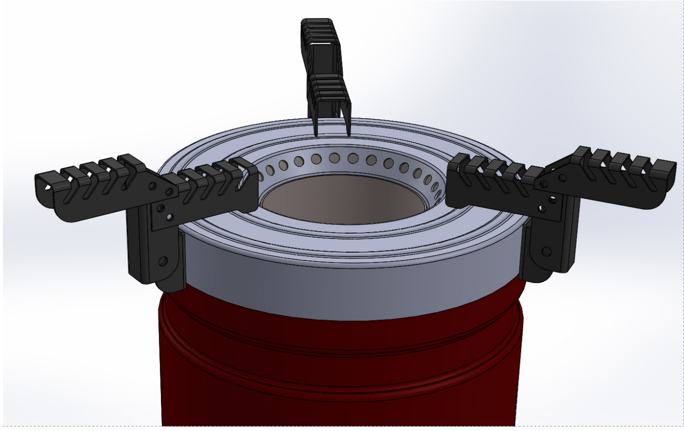


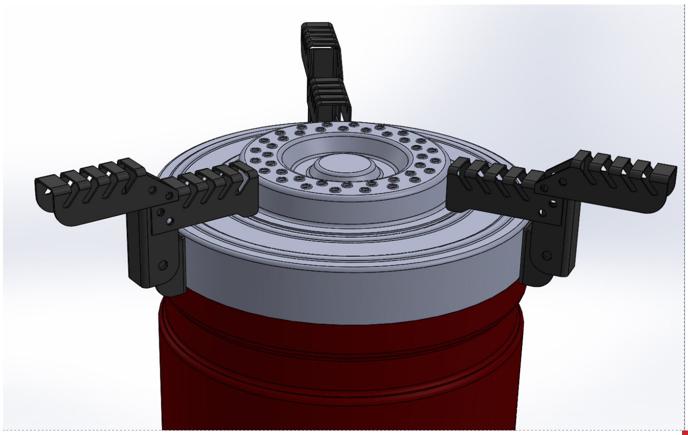
Idea 4 Collapsible support (four)



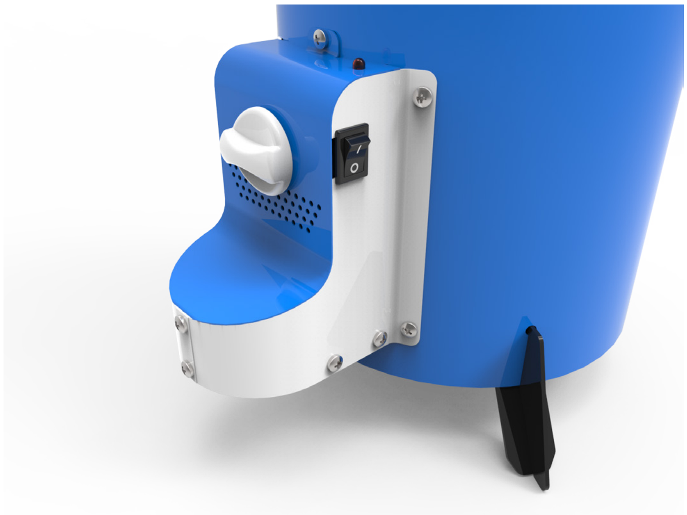


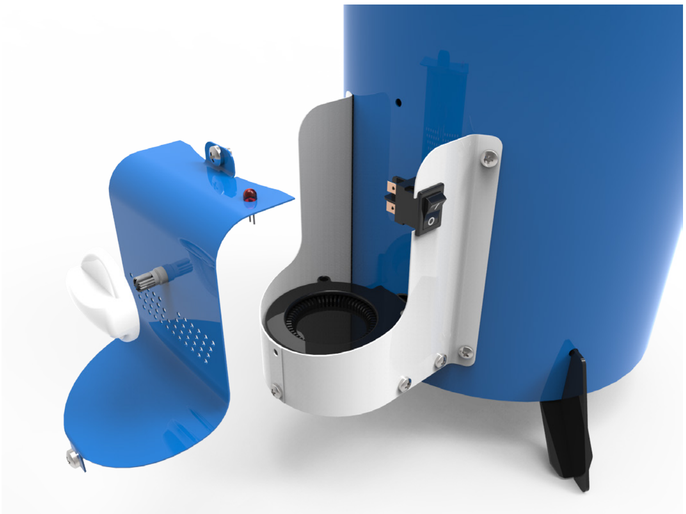
Idea 4 Collapsible support (three)

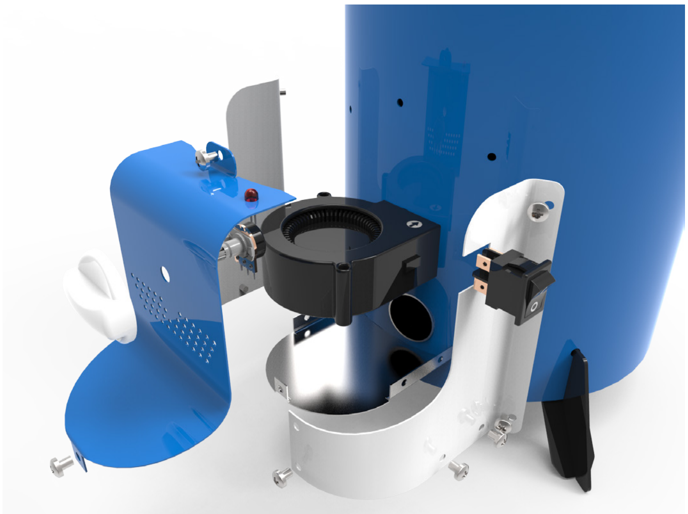


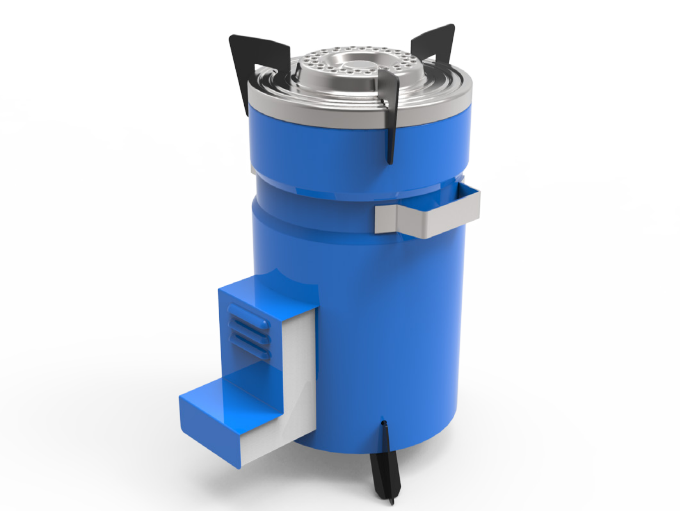


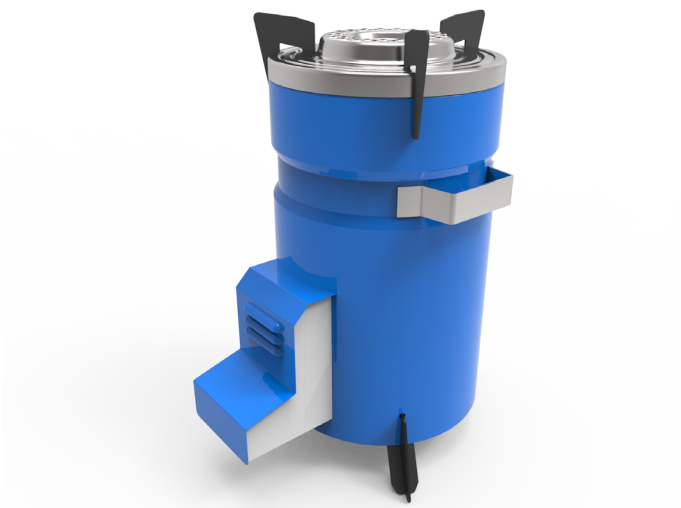
APPENDIX G.4: BODY SHAPE IDEATION

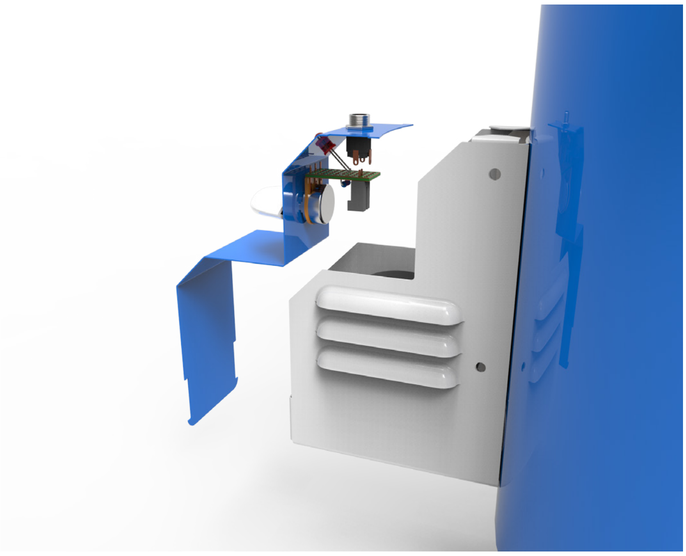












APPENDIX G.5: ELECTRICITY GENERATION

One of the ideas of implementing a thermo electric generator into the gasifier is by transferring some of the heated secondary air to the outside trough a tube passing one side of the peltier element. The same air exits the back and thereby propelling a fan which sucks cool air in the opposite direction. The cool air passes the heatsink cooling the other side of the peltier element.

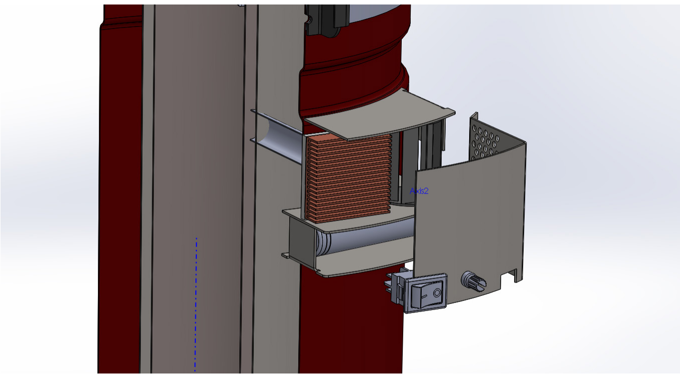


Image G.5.1: Electric generator using the airflow cross section

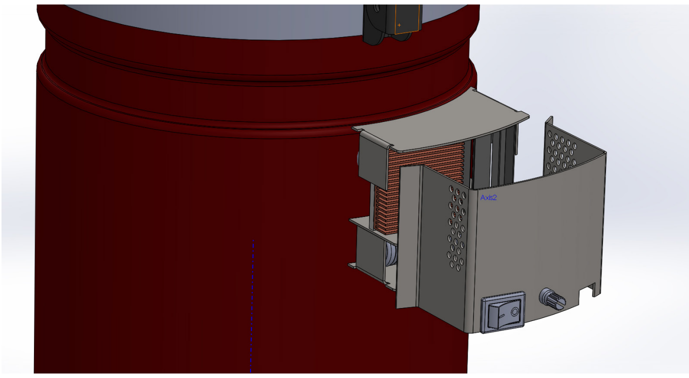


Image G.5.2: Electric generator using the airflow

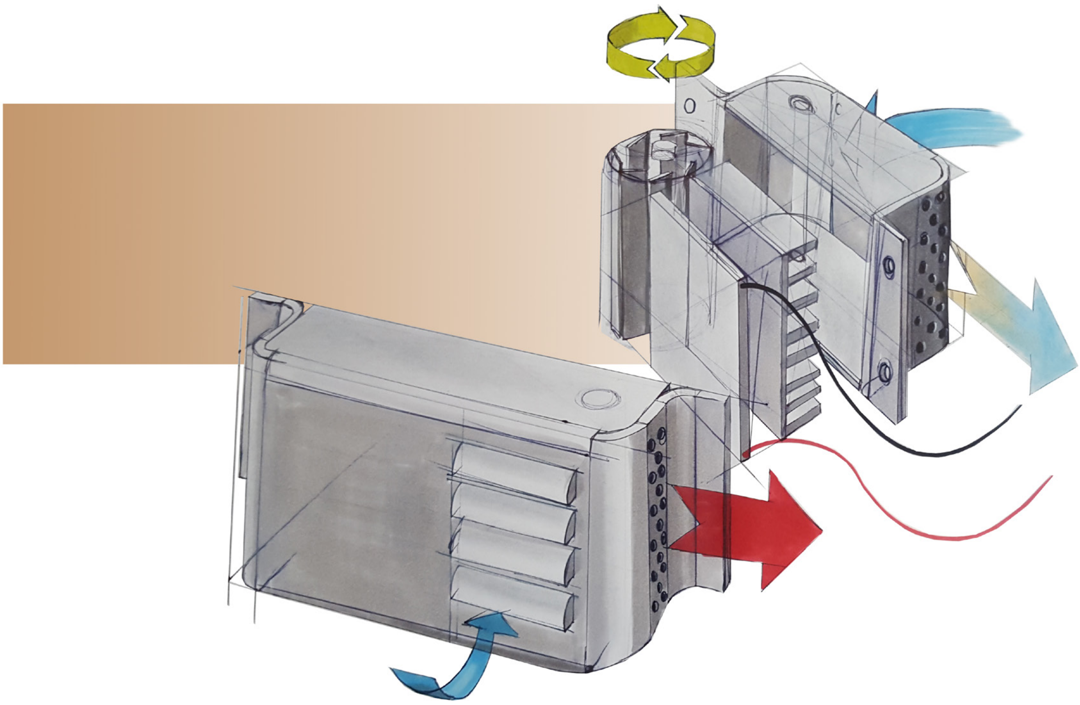


Image G.5.3: Sketch of thermo electric generator box with the air streams

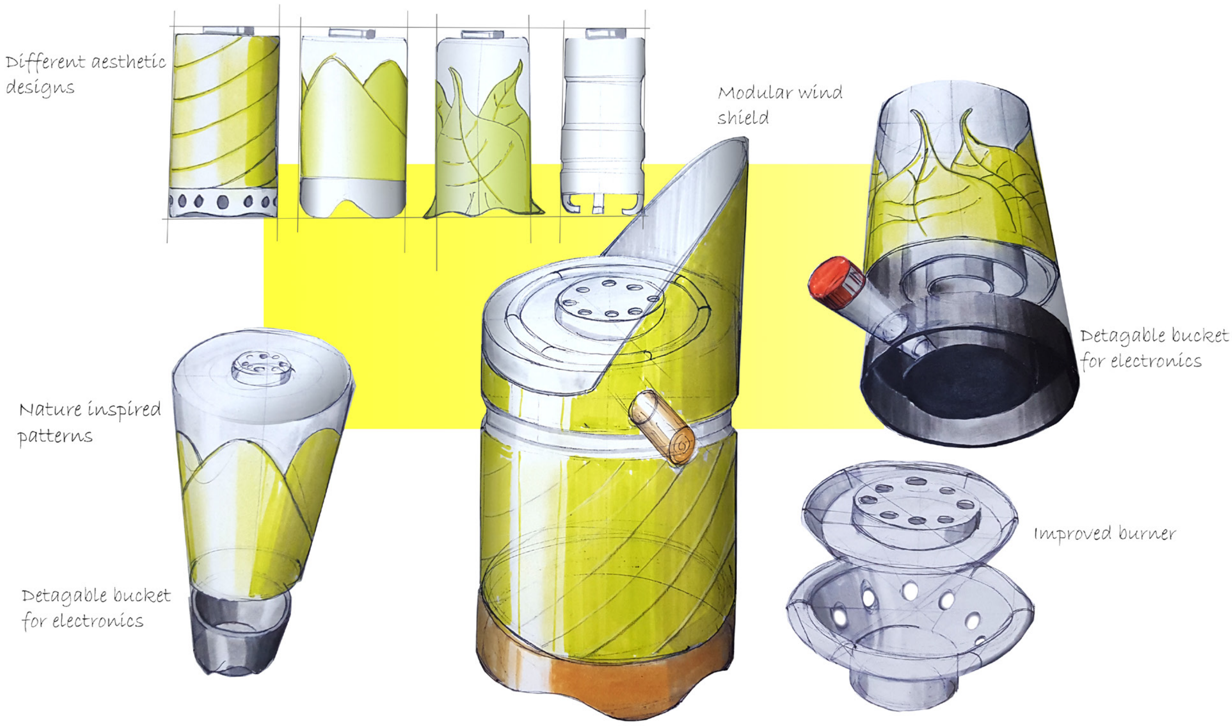


Image G.6.1: Presentation sketch 1 decoration of the body

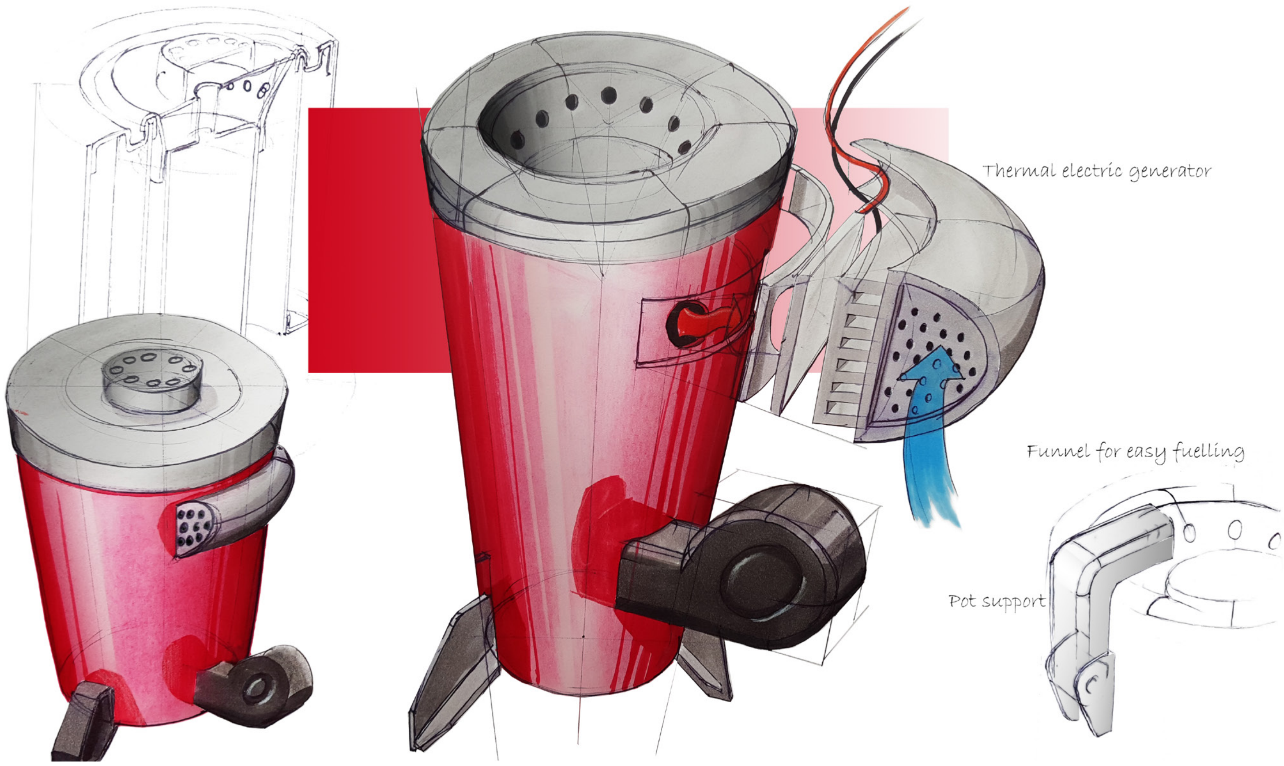


Image G.6.2: Presentation sketch 2 high gloss body

Image G.6.3: Presentation sketch 3 gasifier with a clay body

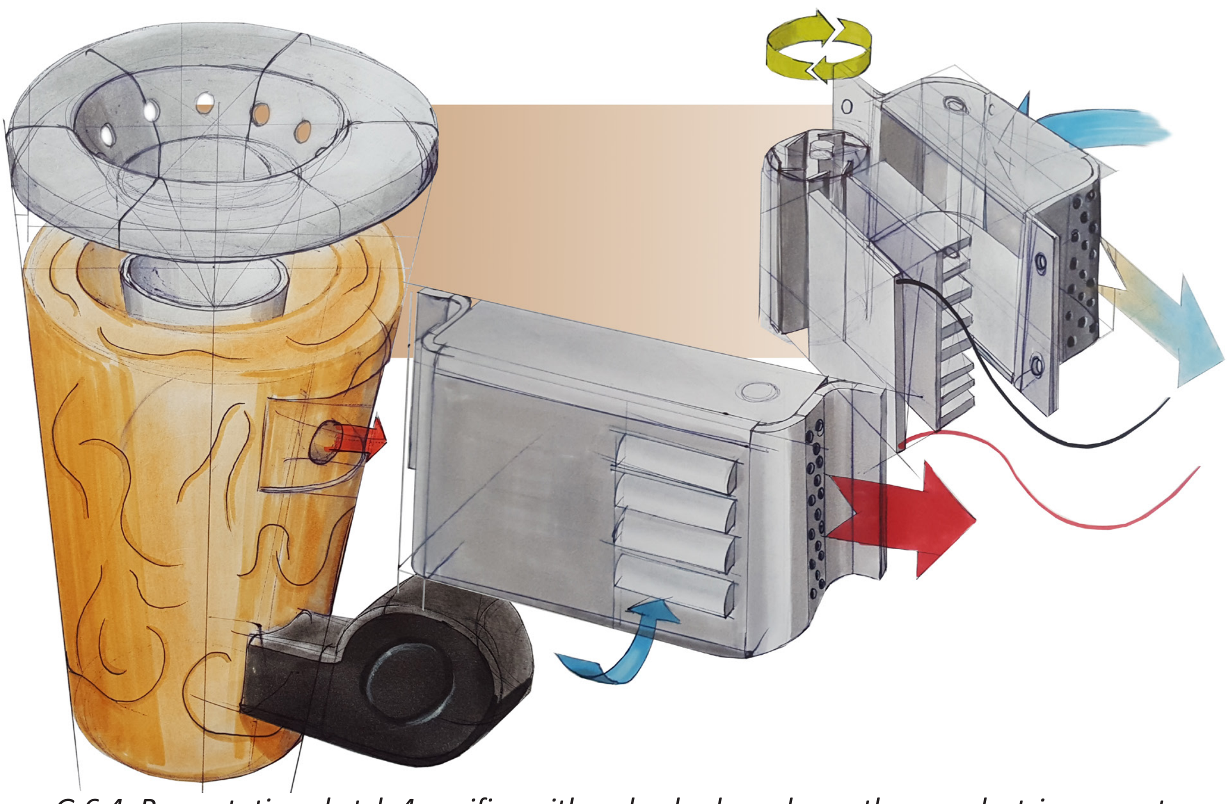


Image G.6.4: Presentation sketch 4 gasifier with a clay body and new thermo electric generator components

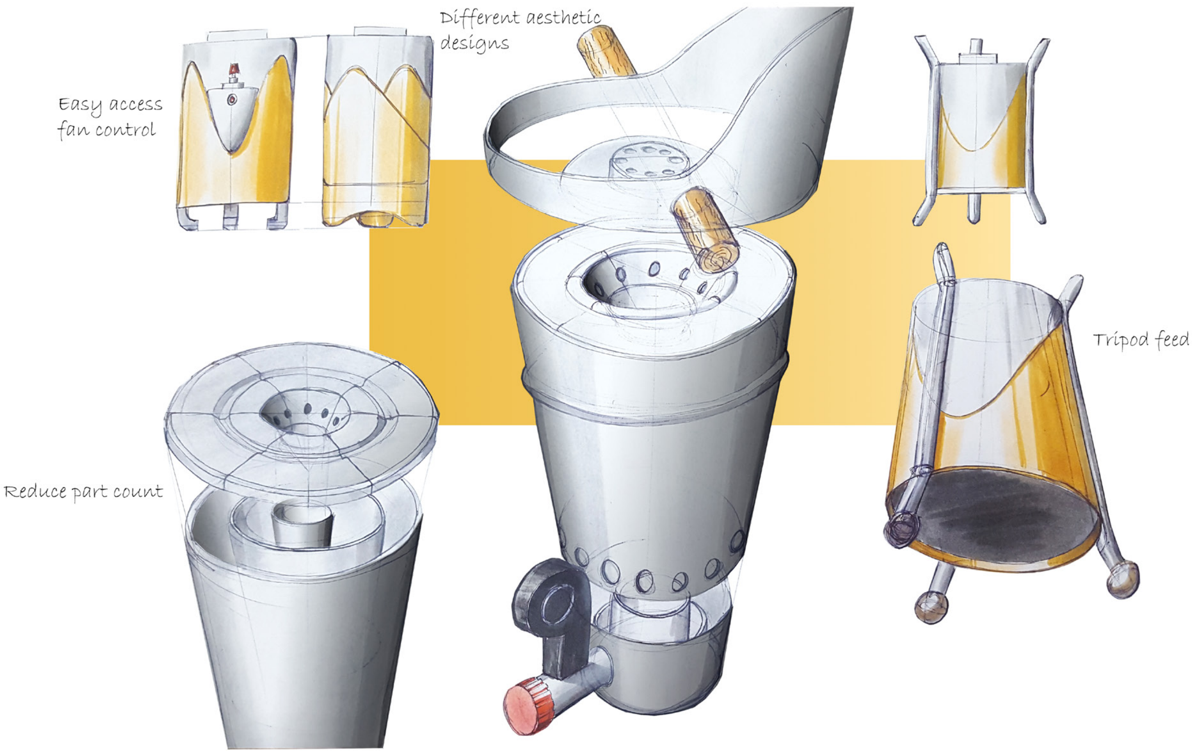


Image G.6.5: Presentation sketch 5 stainless steel body with airflow box idea and different feet

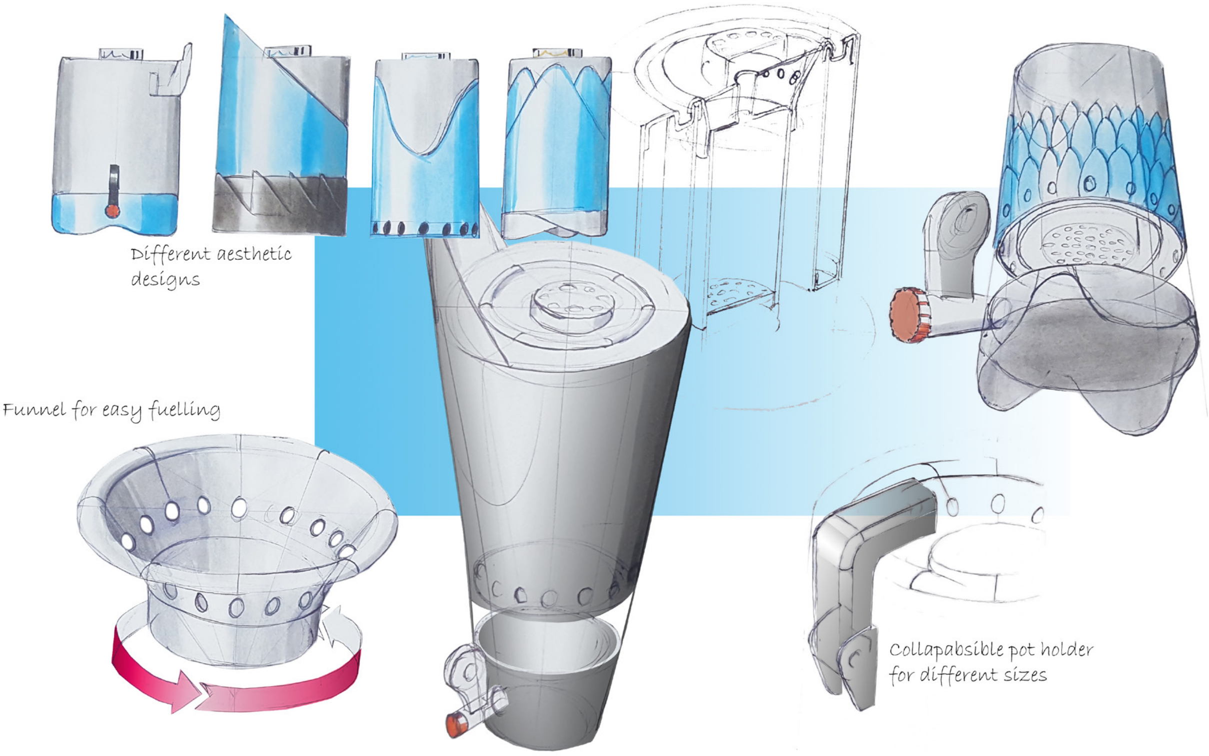


Image G.6.6: Presentation sketch 6 shape and pattern exploration

APPENDIX G.7: CONTINUES GASIFIER

One of the ideas was to develop a continues version of the gasifier. A concept of this is presented in the image below. Most of the parts can be similar to the batch operated stove but the airflow is slightly changed. It is reasoned that due to the low ash content of the pellets emptying the char during the cooking process is not needed. Additionally, pellets can be added to the operation through the openings at the top.

The gasifier starts the same way as the batch operated version and only when the fuel inside the reactor is nearly empty will the fuel from the side chamber be added.

Image G.7.1: Continues concept of the gasifier

APPENDIX H: EMBODIMENT

APPENDIX H.1: BENDING OPERATIONS FOR DIFFERENT PARTS

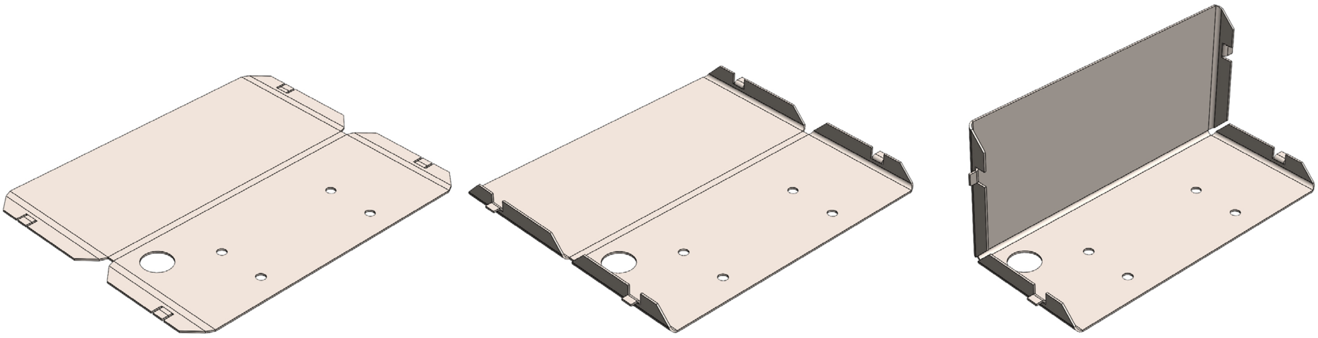


Image H.1.1: Bending procedure of the PCB tray

Image H.1.2: Bending procedure of the vertical feet component

Image H.1.3: Bending procedure of the reactor holder clamp

Image H.1.4: Bending procedure of the universal clamp

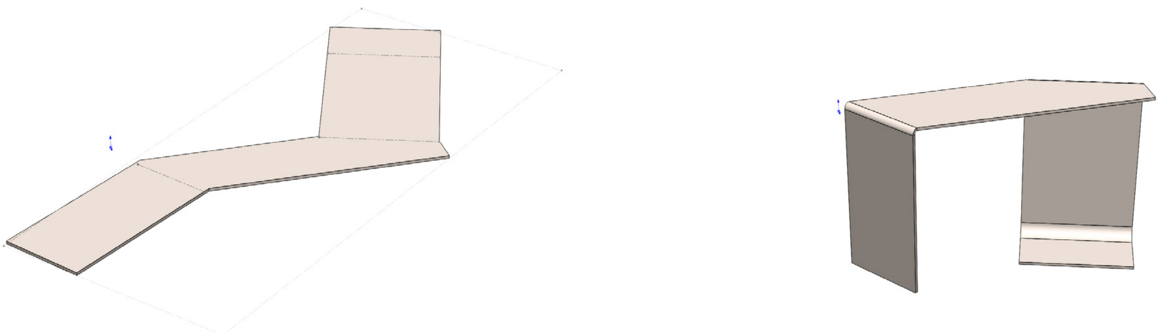


Image H.1.5: Bending procedure of the fan connection

Image H.1.6: Bending procedure of the connection rail

APPENDIX H.2: OVERVIEW OF SUB-ASSEMBLIES AND PARTS

Assembly number	Sub assembly name	Part number	Part name	Quantity
1	Body	9	Body	1
		10	Handles	2
		23	Connection rail	2
2	Inner tube	8	Inner tube	1
		11	Reactor holder	3
		30	M4X0.7X8 Screw	3
		32	M4 Hex nut	3
3	Reactor	7	Reactor tube	1
		26	Grade	1
		1	Universal clamp	2
4	Burner	1	Universal clamp	1
		2	Burner top	1
		3	Burner bottom	1
5	Reactor cap	1	Universal clamp	1
		4	Reactor cap	1
		28	Venturi tube	1
6	Air tube	24	Air tube	1
		25	Air tube cap	1
7	Electronics	16	PCB tray	1
		17	PCB + electronics	1
		27	PCB spacer	4
8	Electro box	22	Electro box	1
		21	Blower fan	1
		29	Blower connection	1
		31	M4X0.7X35	2
		32	M4 Hex nut	2

Table H.2.1: Sub assemblies with the parts

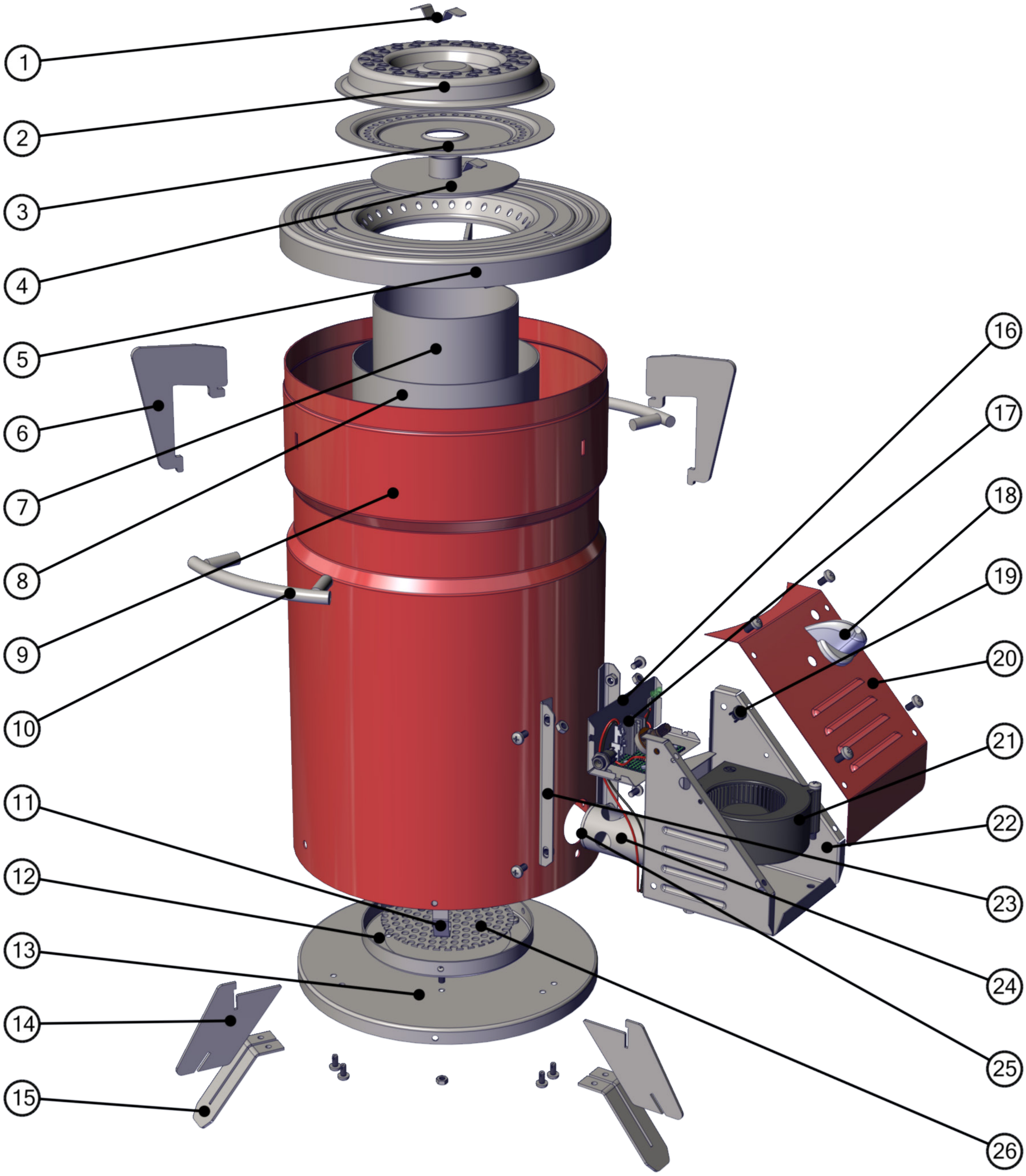


Image H.2.1: Exploded view with part numbers

Part nr.		Part nr.		Part nr.		Part nr.	
1	Universal clamp 4x	9	Body	17	PCB + electronics	25	Air tube cap
2	Burner top	10	Handle 2x	18	Rotary switch knob	26	Grade
3	Burner bottom	11	Reactor holder 3x	19	Led holder	27	PCB spacer 4x
4	Reactor cap	12	Connection ring	20	Electric lid	28	Venturi tube
5	Top plate	13	Bottom plate	21	Blower fan	29	Blower connection
6	Pot support 3x	14	Feet vertical 3x	22	Electric box	30	M4X0.7X8 Screw 20x
7	Reactor tube	15	Feet horizontal 3x	23	Connection rail 2x	31	M4X0.7X35 Screw 2x
8	Inner tube	16	PCB tray	24	Air tube	32	M4 Hex nut 22x

Table H.2.2: Part numbers with name

APPENDIX H.3: TOTAL ASSEMBLY STEPS

Number	Identical actions	Time (sec)	Description	Part number
1	1	3	Place Bottom plate	13
2	1	3	Place connection ring	12
3	3	6	Screw	30, 32
		Make sub assembly 2: Inner tube		
4	1	3	Grab inner tube	8
5	3	6	Grab reactor holder	11
6	3	6	Screw	30,32
7	1	3	Place inner tube assembly	8, 11, 30, 32
8	3	6	Screw	30, 32
		Make sub assembly 1: body		
9	1	3	Grab body	9
10	2	8	Weld handles	10
11	2	8	Weld connection rail	23
12	1	3	Place body assembly	9, 10, 23
13	3	6	Screw	30, 32
		Make sub assembly 6: Air tube		
14	1	3	Grab air tube	24
15	1	3	Place air tube cap	25
16		4	Weld cap to air tube	
17	1	3	Place air tube assembly	24,25
18	1	3	Place top plate	5
		Make sub assembly 8: Electro box		
19	1	3	Grab electro box	22
20	1	3	Place blower fan	21
21	1	3	Place blower connection	29
22	2	6	Screw	31, 32
23	1	3	Place electro box assembly	22, 21, 29, 31, 32
24	4	8	Screw	30, 32
		Make sub assembly 7: Electronics		
25	1	3	Grab PCB tray	16
26	4	8	Place PCB spacers	27
27	1	3	Place PCB + Electronics	17

28	1	3	Place electronics assembly	16,17,27
29	1	3	Place electric lid	20
30	4	8	Screw	30, 32
31	1	3	Place rotary switch knob	18
			Make sub assembly 3: Reactor	
32	1	3	Grab reactor tube	7
33	1	4	Weld grade	26
34	2	8	Point weld universal clamps	1
35	1	3	Place reactor assembly	7, 26, 1
			Make sub assembly 5: reactor cap	
36	1	3	Grab reactor cap	4
37	1	4	Point weld universal clamp	1
38	1	4	Weld venturi tube	28
39	1	3	Place reactor cap assembly	1, 4, 28
			Make sub assembly 4: Burner	
40	1	4	Grab burner top	2
41	1	4	Point weld universal clamp	1
42	1	4	Point weld burner bottom	3
43	1	3	Place burner assembly	1, 2, 3
Total assembly time		**184**		

Table H.3.1: Assembly steps

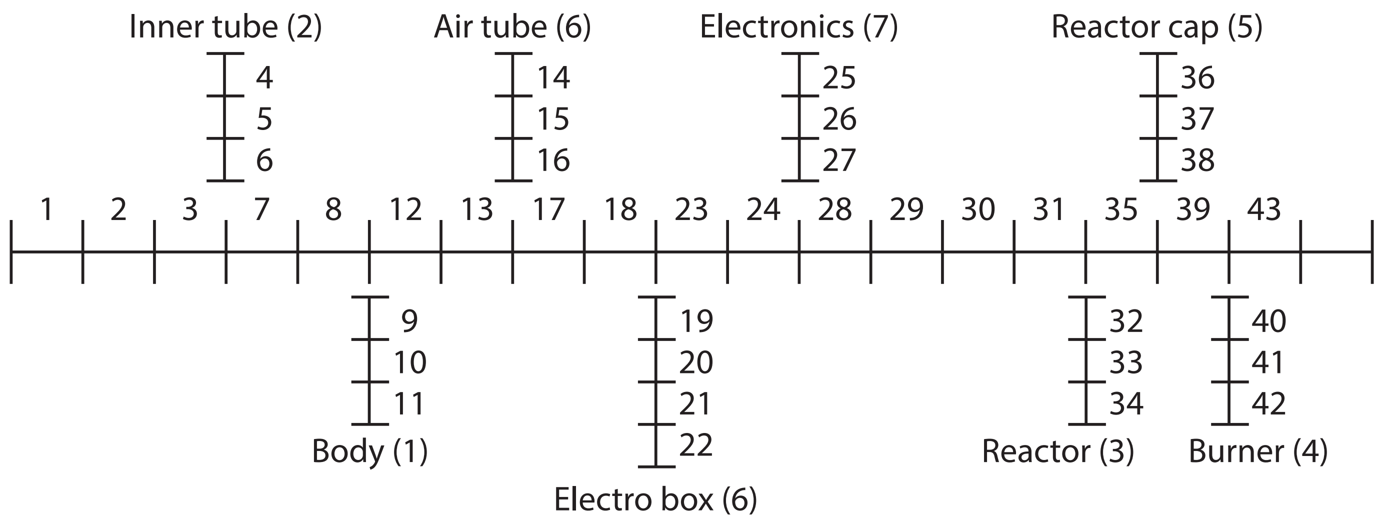


Image H.3.1: Assembly line drawing

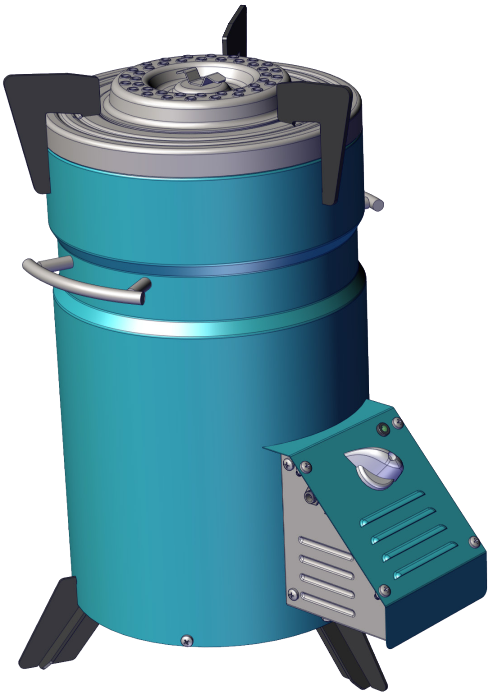


Image H.4.1: Assembled gasifier

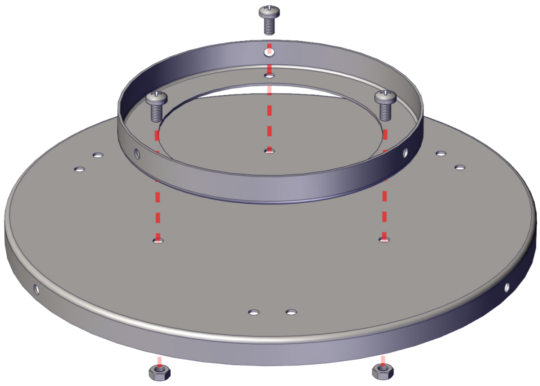


Image H.4.2: Assembly of the gasifier step 1

Image H.4.3: Assembly of the gasifier step 3

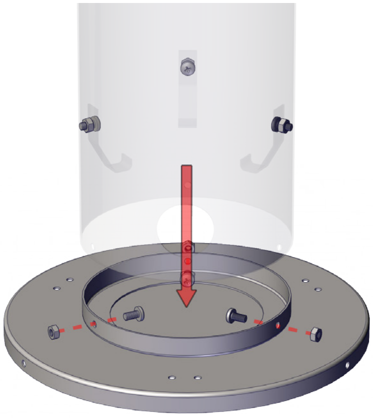


Image H.4.4: Assembly of the gasifier step 7

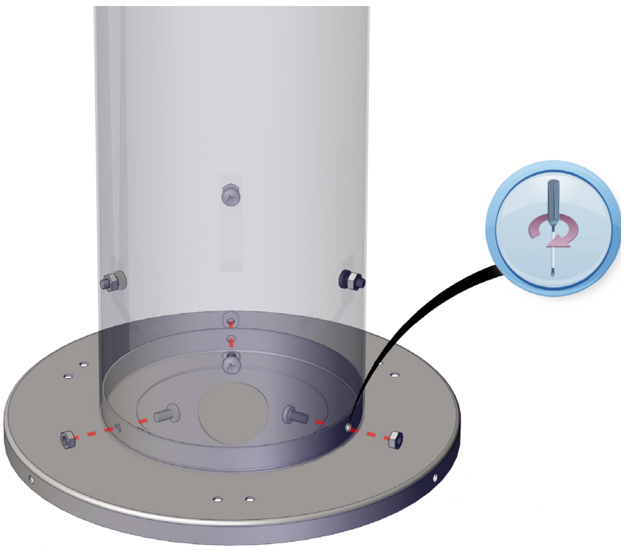


Image H.4.5: Assembly of the gasifier step 8

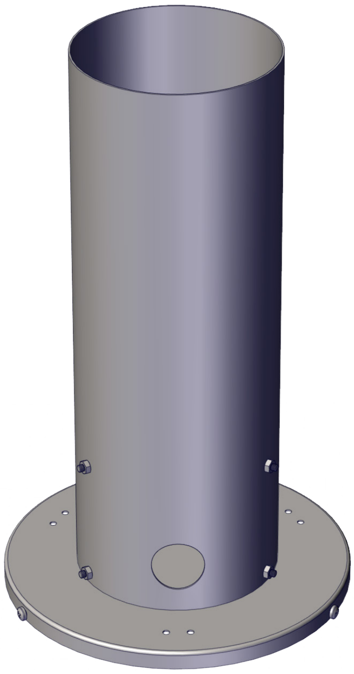


Image H.4.6: Assembly of the gasifier

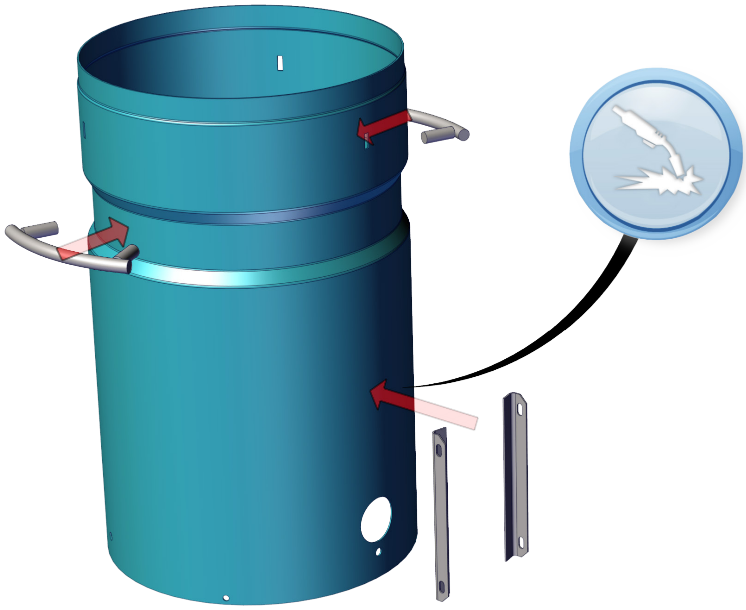


Image H.4.7: Assembly of the gasifier step 9, 10 and 11

Image H.4.8 assembled handles and connection rail

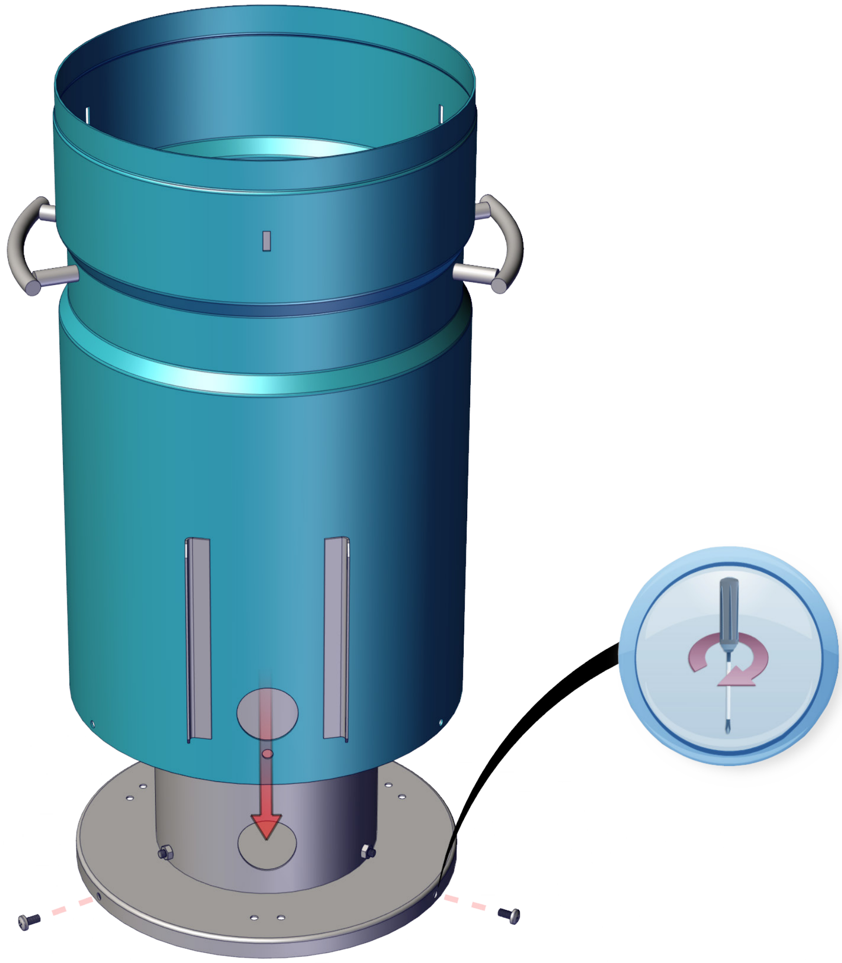


Image H.4.9: Assembly of the gasifier step 12 and 13

Placement of the air tube and the reactor

The air tube can be placed by simply pushing it through the holes of the body and the inner tube. A groove at the end of the air tube keeps it in place.

The reactor can simply be slided through the funnel at the top plate. The reactor holder has an angle so it slides into the right positions, even when it is not placed completely straight.

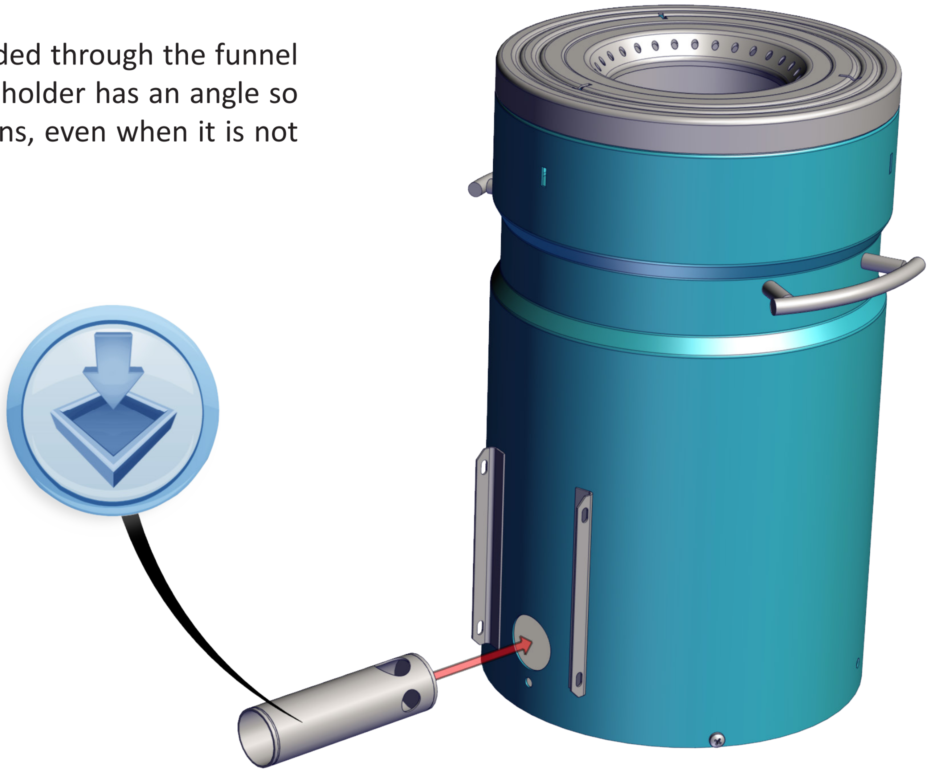


Image H.4.10: Placement of the air tube step 17

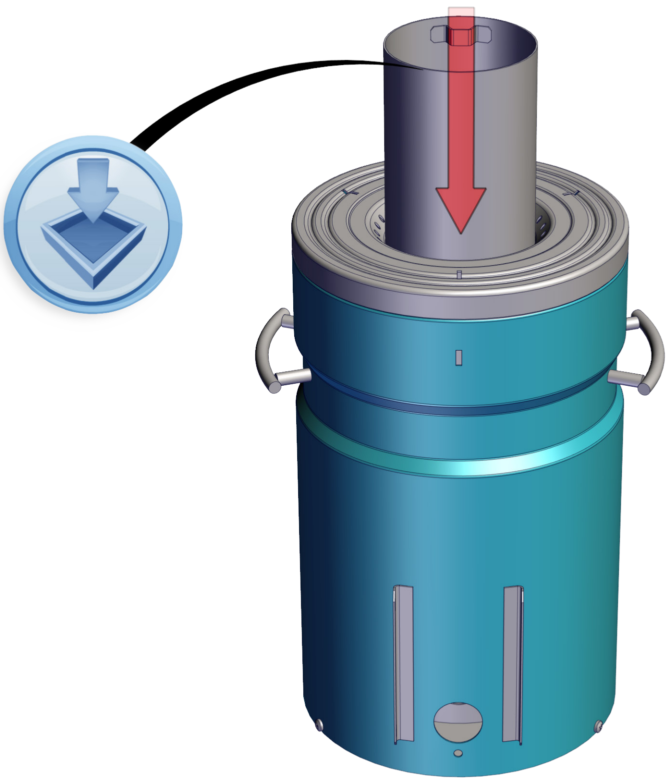


Image H.4.11: placement of the reactor step 34

Electric box assembly

The electric box can be assembly with a few steps. First the fan with the fan connection are placed inside the box, and mounted with two M4 screws.

The second step is to grab the assembled electronics on the PCB tray and slide it between the sides of the electric box. The fan can be connected with the 2 pin connector and the power supply is bolted onto the side.

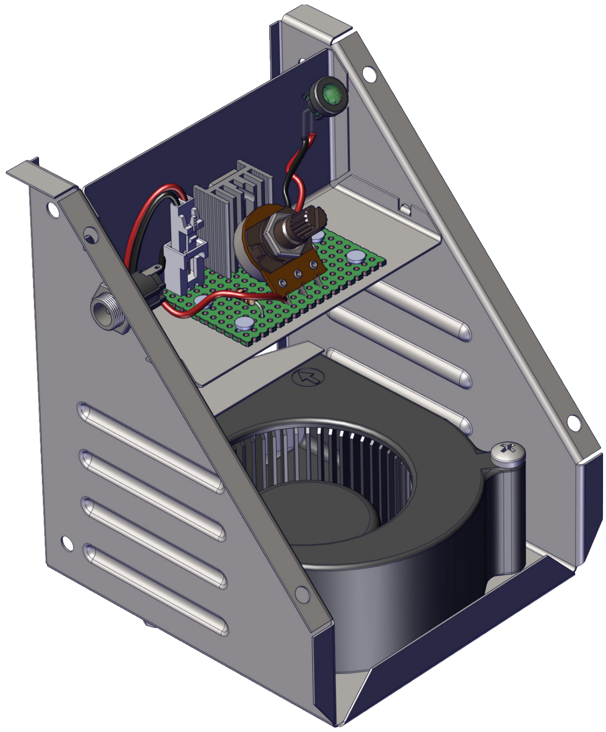


Image H.4.12: Assembly of the electronic box

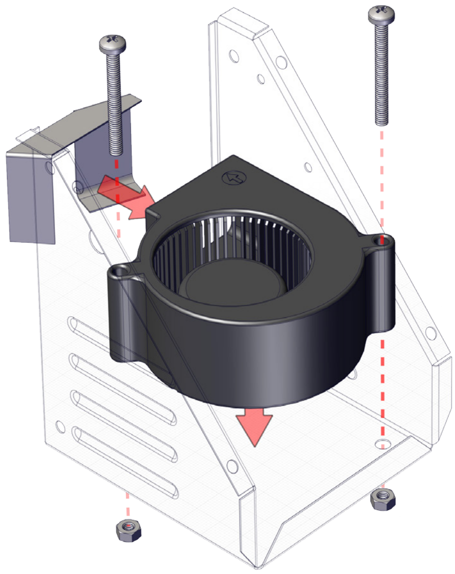


Image H.4.13: Placement of the fan

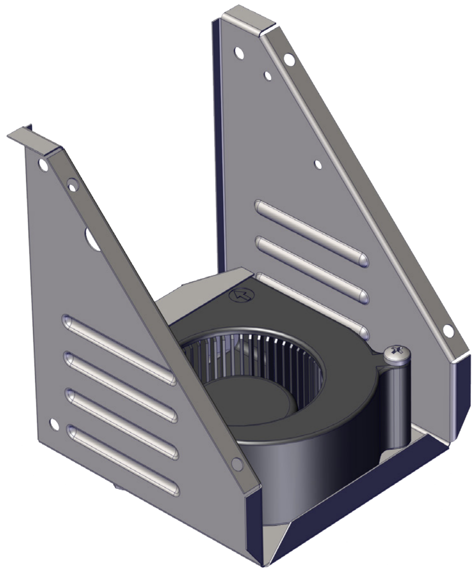


Image H.4.14: Placement of the fan

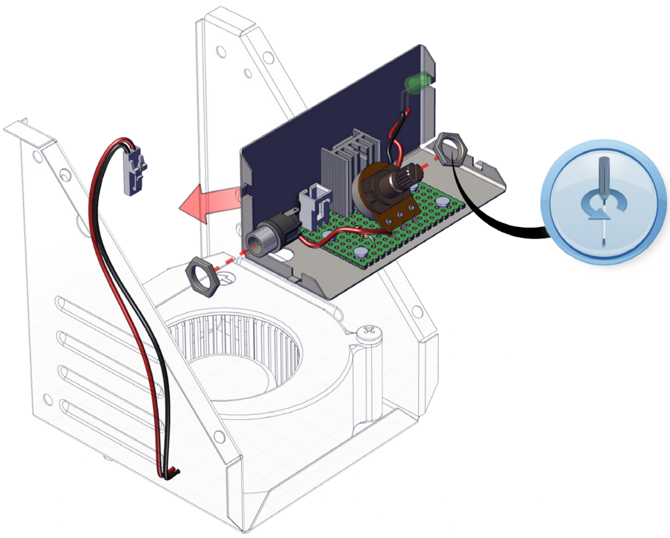


Image H.4.15: Placement of the PCB tray

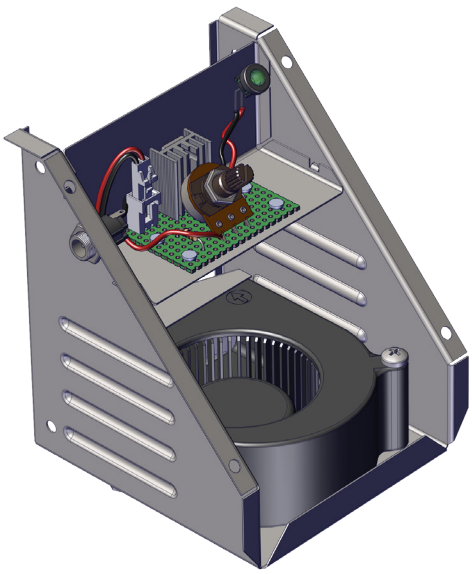


Image H.4.16: Placement of the PCB tray

The next step is to place the entire electric box onto the connection rail and bolt them together. Slots are placed in the connection rail to account for any tolerance loss during production

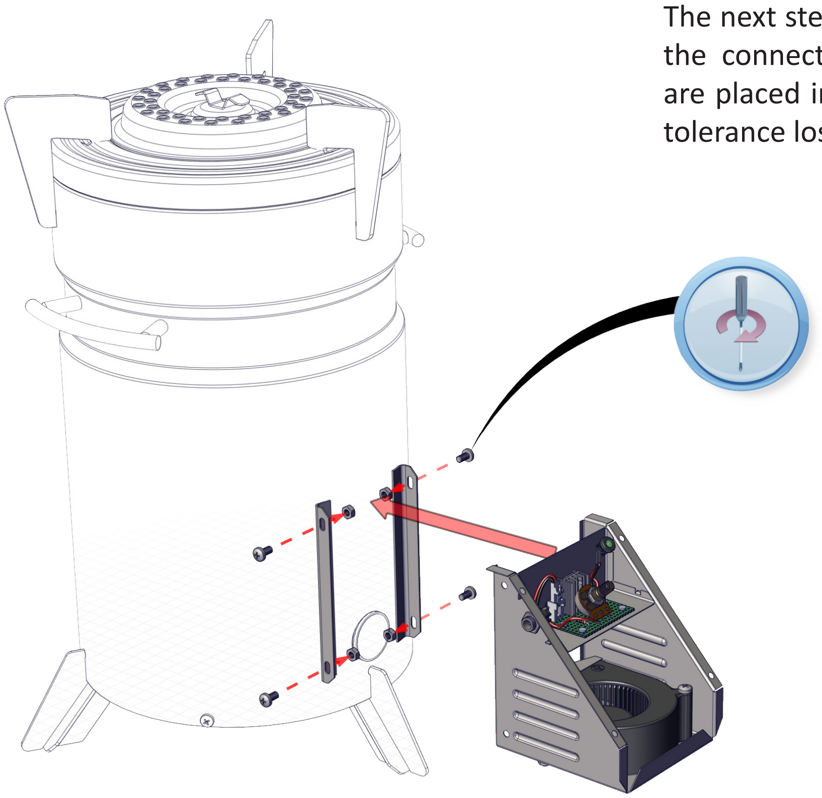


Image H.4.17: Schematic of how the electric box is placed onto the gasifier

The lid can be secured with four bolt and four screws. The bolts can be holden from the side.

The potentiometer is secured onto the lid and the knob is simply pressed on.

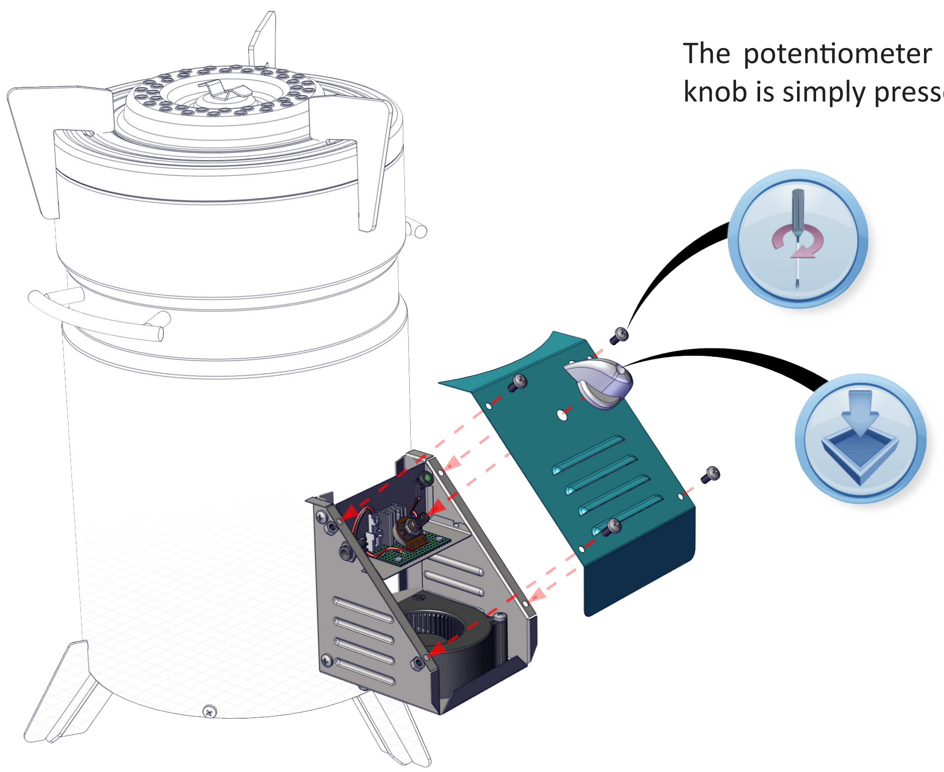


Image H.4.18: Schematic of how the lid is placed onto the electric box

Assembly steps by the user

To decrease the transportation package and avoid sticking out edges the feet and pot support structure have to be mounted by the user. For the feet, the two parts have to lock into each other before they are placed in on the body. On of the pieces snaps into the side of the body and the other one is mounted with two self tapping screws. The Pot support does not require any screws and is kept in place with pressure. First the bottom of the pot support snaps into the side of the body. The top is than slide over the top plate where it can snap into the slot.

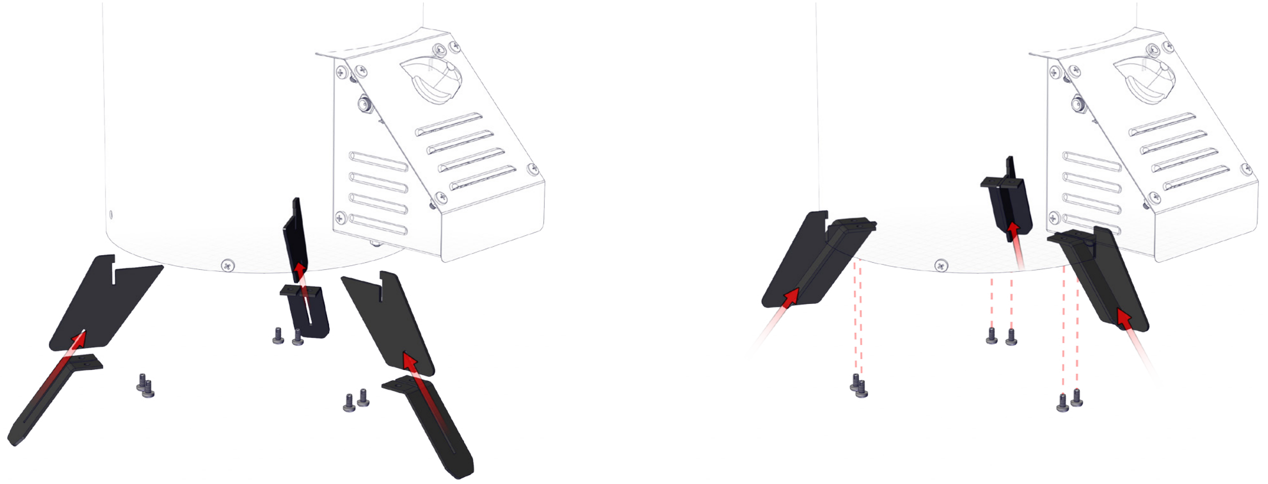


Image H.4.19: Top view of the feet placement procedure

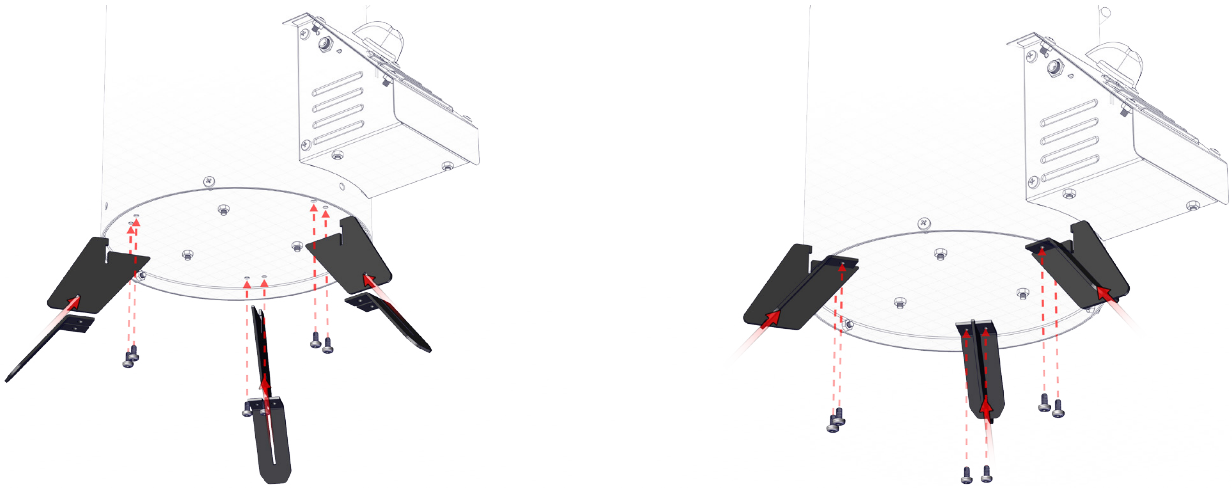
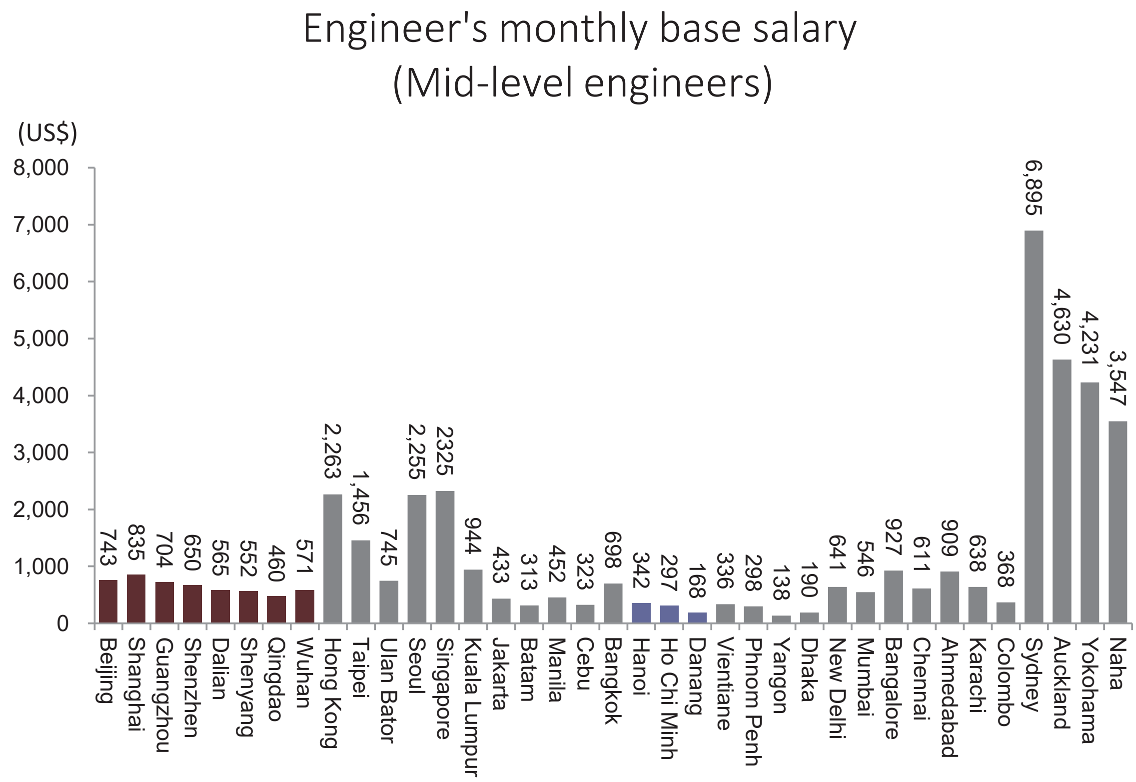


Image H.4.20: Bottom view of the feet placement procedure

Image H.4.21: Illustration of the pot support placement procedure

APPENDIX H.5: MASS PRODUCTION IN VIETNAM

Over the past five years, there has been shift for companies to chose Vietnam as their primary production supplier over China. A chart presented by a survey of investment related cost in Asia shows the monthly income of engineers in major cities of Asia. It clearly shows a key reason for this shift in production as wages in cities Vietnamese cities (Hanoi, Ho Chi Minh and Danang) are about three time lower than major cities in China (on the left)



Graph H.5.1: Engineer's montly salary of cities in Asia

More technical are seeking to invest in Vietnam for this reason. However, unlike China additional investment in manufacturing equipment are required. Big companies like Samsung and Mitshubishi heavy industries (SOURCE: www.intouch-quality.com/blog/3-key-factors-for-sourcing-in-vietnam/) are willing to capitalize big on these lower labor costs. They are spending billions on setting up the right infrastructure that is required for their operations.

Vietnam its manufacturing industry is fragmented which makes it harder to identify suitable suppliers. This in contrast with China where it is easy to find almost anything you want. Looking at Alibaba an online portal for identifying suppliers it is dominated by Chinese companies. For example, searching for "small centrifugal fan" yields 12287 potential suppliers from China and only 1 in Vietnam. Though a supplier is not necessarily a manufacturer it does show a clear difference.

Stove production in Vietnam

Of course CCS does not have the recourses to setup an entire production facility for the production of a stove, but lower cost manufacturing shops can also produce relatively small amounts of stoves to start with. As an example of how an improved stove can be produced in Vietnam a stove from SolarServe is analyses. This stove is currently being mass produced with support of SNV, in Danang the middle of Vietnam. These pictures below give an overview of the production sight. It clearly shows the working environment within this factory, half-fabricates are stacked upon each other moving through the factory to every production stage It is likely that the CCS gasifier will be produced in a similar environment, so attention has to be paid on designing the gasifier in such a way that it is also efficient for assembly.

Image H.5.1: Solarserve stove production line in Vietnam showing different stages in the manufacturing and assembly process. (YouTube, 2014)

TABLE OF ESTIMATED PRODUCTS COST

Tên sản phẩm: Bếp đun chẩu

KT:625x450x1100

DMVT dated 18/12/2015 | Symbol: BDC-01 | **SL: 100,000 chiếc**

STT	PART NAME	SPECIFICATION	DETAIL	UNIT	CONSUMABLES VT	UNIT PRICE (VND)	Amount (VND)
	Cost of frame INOX SUS201				***4,699***		***142.772***
1	Lắp trên	134x134x0.5	1	Kg	0,093	42.091	3.914
2		140x140x0.5	1	"	0,086	42.091	3.620
3		146x146x0.5	1	"	0,09	42.091	3.830
4		282x282x0.5	1	"	0,365	42.091	15.363
5	Thân bếp	283x230x0.5	1	"	0,292	42.091	12.291
6		100x100x0.5	1	"	0,041	42.091	1.726
7		360x293x0.5	1	"	0,486	42.091	20.456
8	(Thép JISG)	635x305x1.0	1	"	1,946	13.821	26.896
9	Ke	53.6x15x1.0	3	"	0,019	42.091	800
10	Ống hút gió	$31.8x70x1.0	1	"	0,071	42.091	2.988
11	Bottom Stove	232x232x0.5	1	"	0,233	42.091	9.807
12		248x248x0.5	1	"	0,324	42.091	13.637
13	Paneled hole fan	126x98x1.0	1	"	0,102	42.091	4.293
14	Porcelain stove	75x66x1.0	3	"	0,122	42.091	5.135
15		71x73x1.0	3	"	0,125	42.091	5.261
16		57x40x1.0	3	"	0,055	42.091	2.315
17		70x64x1.0	3	"	0,108	42.091	4.546
18		65x55x1.0	3	"	0,086	42.091	3.620
19		73x30x1.0	3	"	0,054	42.091	2.273
	Packaging						**13.372**
20	3-layer carton box packaging	350x350x365	1	box	1	11.822	11.822
21	Plastic bags printed XH1 HDPE	450x450x0.07	1	bag	1	550	550
22	Other materials						1.000
	The cost of chemicals						***24.605***
23	Welding wires INOX	F0,9	1	kg	0,03	134.545	3.983
24	Gas CO2		1	kg	0,178	4.850	861
25	Cost of electrochemical INOX		1	dm2	73,2	270	19.761
	Plus cost of materials						**180.749**
	Salary (CB + KPI)	*Expected 2.5h 02 persons (10,500 VND x 1.18 x2.5x2) x 80%*					51.520
	Social Insurance, Health, Union	*(22% CFR Salaries)*					1.847
	Equipment expenses + electricity, water	*Expected 2.5h machine (machine and equipment 10 billion / calculated 50%)*					66.074
	Interest expenses	*As of 6.8% / 12 months x 3 months*					3.073
	Cost matrixes	*624.5 million dong / 100,000 sp + 200tr stamp break*					8.245
	Management costs	*Estimated 65% CP and Market Research*					33.488 - Calc
	Plus consumer prices						**344.996**
	Sales price	Calculate the cost of production by 2.5%					8.625
	Expected earnings	As of 5% sale production					17.250
	Priece delivery in XH	*Có VAT*				98,8%	**408.000**
	PRICE OFFERED TO SELL						
	GENERAL PRICE DIRECTOR						

Ghi chỳ:

INOX steel SUS201 01/2016 month old price, uncoated PVC: Price 46,300, VND / kg (price including VAT)

1.0mm thick steel plate JIS G3141 stock costing 13 821 VND / kg (excluding VAT, with cutting cp)

Matrixes according P.ky spreadsheet 6.245 tr arts, durability properties for 100,000 pieces. Estimated 200 million money mortar pestle.

Quotations on the application for the first batch 50,000sp SL, when stabilization will conduct review

Xuân Hoà ngày 11 thỏng 01 năm 2016

NGƯỜI LẬP **CHIEF FINANCIAL OFFICER** **DIRECTORS COMPANY**

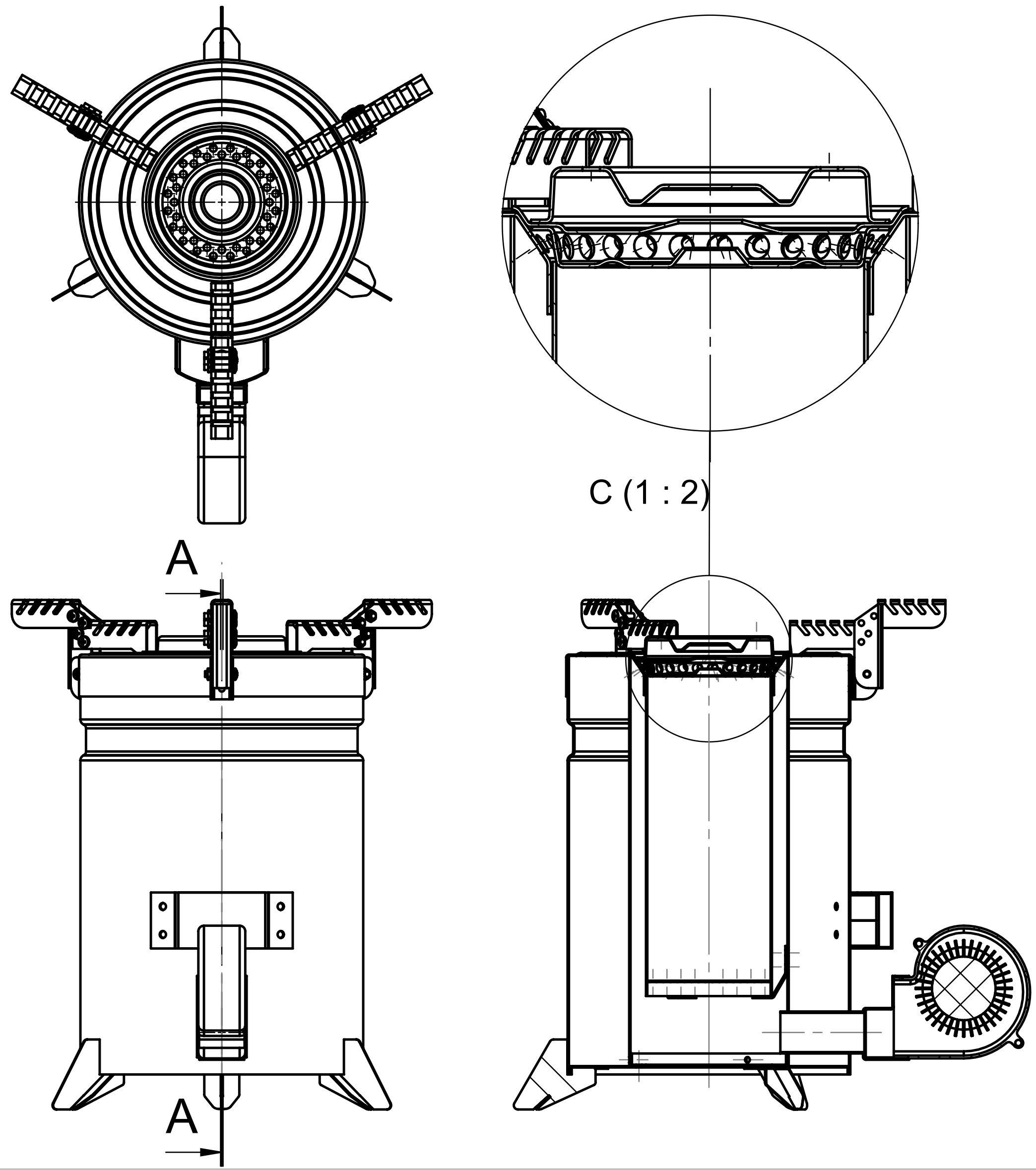
APPENDIX H.6: QUOTATION FROM A PRODUCTION FACILITY

The quotation was given in Vietnamese and is roughly translated to English. The manufacture states it is able to produce the gasifier for 408 000 VND which is around $ 18.3. This quotation is based on the assembly drawing provided in appendix H.6.

culated by the ratio between payroll management and technology department direct current sx

86.827

no	Unit	part name	qty
1	84.8	Gasifier_Concept_19_CCS_burner_middle_PART_00	1
2	53.7	Gasifier_Concept_19_CCS_Pot Support_handle_PART_00	1
3	55.9	Gasifier_Concept_19_CCS_Pot Support_Inner_PART_00	1
4	61.1	Gasifier_Concept_19_CCS_Pot Support_vertical_PART_00	1
5	47.0	Gasifier_Concept_19_CCS_Pot Support_mount_PART_00	1
6	401.7	Gasifier_Concept_19_CCS_plate_top_PART_00	1
7	1514.3	Gasifier_Concept_19_CCS_Tube_outer_PART_00	1
8	104.7	Centrifugal fan	1
9	19.2	Gasifier_Concept_19_CCS_Controlbox_top_PART_00	1
10	18.9	Gasifier_Concept_19_CCS_Controlbox_bottom_PART_00	1
11	48.2	Gasifier_Concept_19_CCS_Fan Holder_PART_00	1
12	95.1	Gasifier_Concept_19_CCS_burner_top_PART_00	1
13	75.2	Gasifier_Concept_19_CCS_burner_bottom_PART_00	1
14	49.3	Gasifier_Concept_19_CCS_Controlbox_frontpanel_PART_00	1
15	43.7	Gasifier_Concept_19_CCS_AirTube_PART_00	1
16	275.1	Gasifier_Concept_19_CCS_plate_bottom_PART_00	1
17	37.5	Gasifier_Concept_19_CCS_mesh_PART_00	1
18	825.5	Gasifier_Concept_19_CCS_Tube_inner_PART_00	1
19	49.6	Gasifier_Concept_19_CCS_Support_innertube_PART_00	1
20		Hexagon Thin Nut ISO - 4035 - M4 - N	15
21	514.5	Gasifier_Concept_19_CCS_Tube_reactor_PART_00	1
22		ISO 7045 - M4 x 20 - Z --- 20N	15
23	28.0	Gasifier_Concept_19_CCS_Support_reactor_PART_00	3
24	69.0	Gasifier_Concept_19_CCS_SheetMetal Feet_PART_00	1

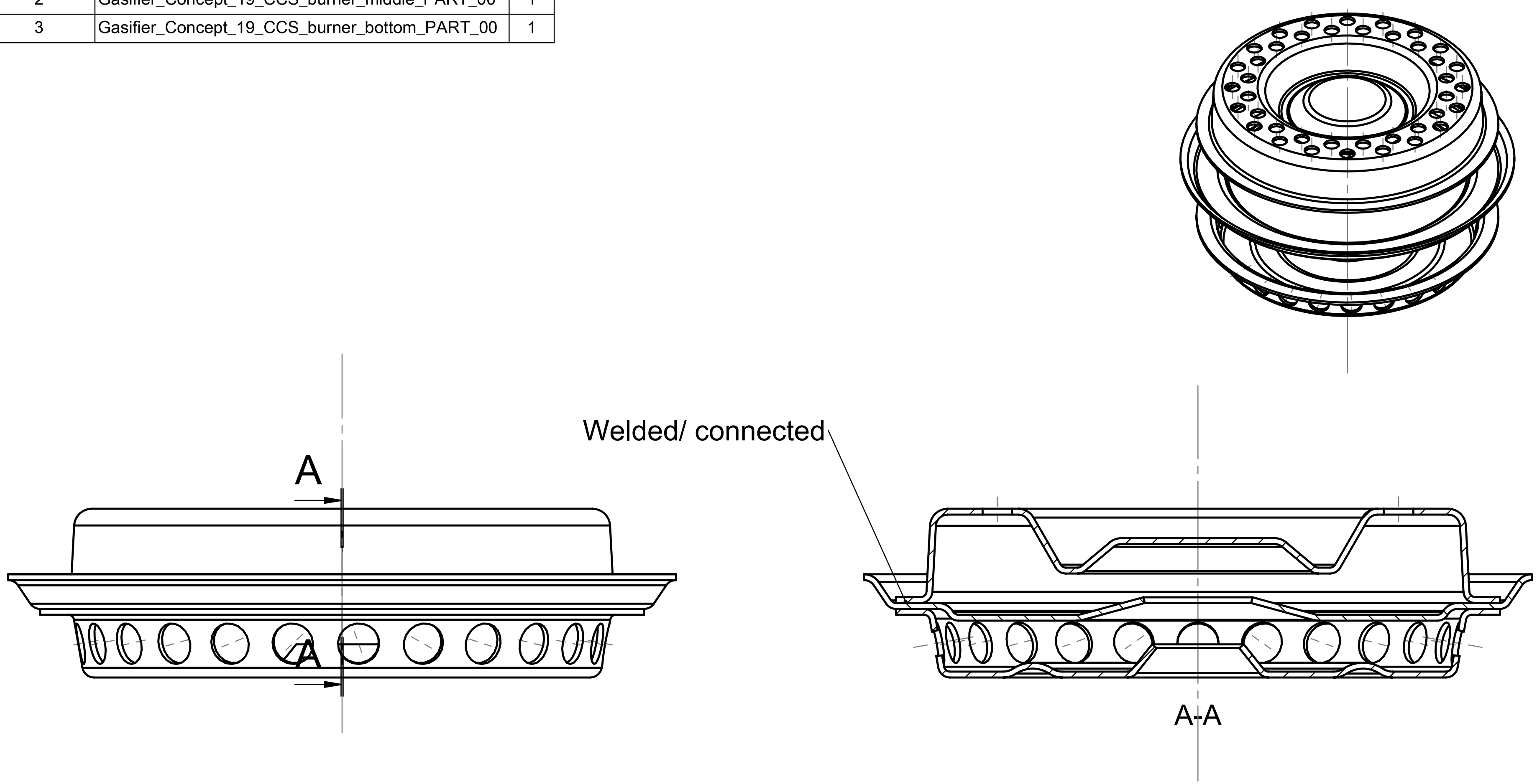


TU Delft
Industrial Design Engineering

benaming
Gasifier_Concept_19_CCS_ASSEM_00

datum 6-12-2015
getekend
groep <<dagdeel>>
<<(achter)namen & studienummers>>
schaal 1:5
maateenheid mm
formaat A4
gewicht gram
tekening nr. / opmerkingen
<<tekeningnummer>>

no	part name	qty
1	Gasifier_Concept_19_CCS_burner_top_PART_00	1
2	Gasifier_Concept_19_CCS_burner_middle_PART_00	1
3	Gasifier_Concept_19_CCS_burner_bottom_PART_00	1



TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_burner_ASSEM	datum 29-11-2015 getekend / groep <<dagdeel>> <<(achter)namen & studienummers>>	schaal 1:1 formaat A4	maateenheid mm gewicht gram tekening nr. / opmerkingen <<tekeningnummer>>

no	part name	qty
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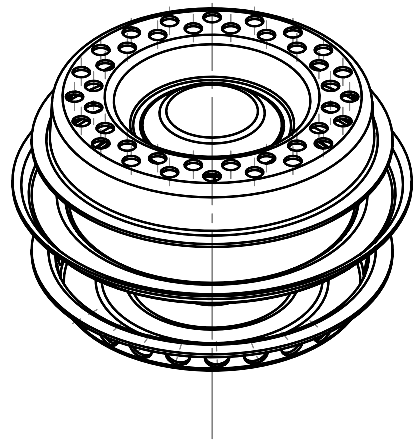
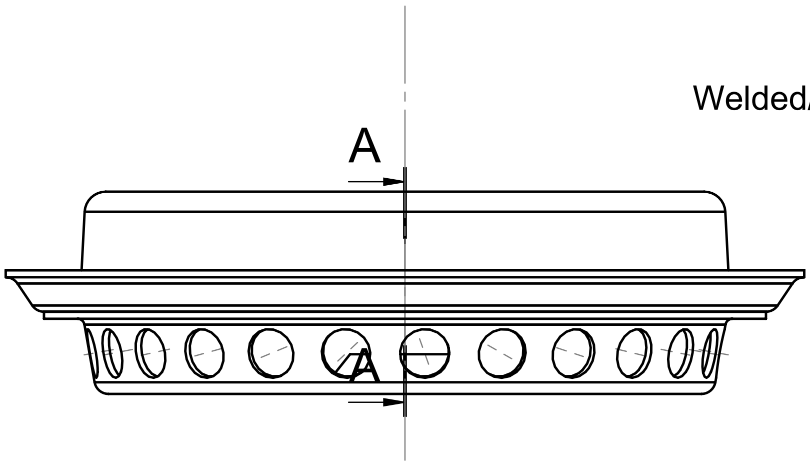
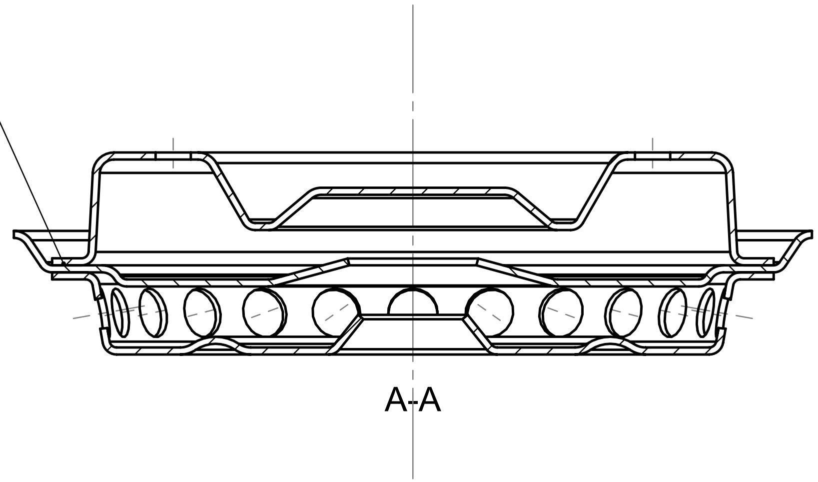
2	Gasifier_Concept_19_CCS_burner_middle_PART_00	1
3	Gasifier_Concept_19_CCS_burner_bottom_PART_00	1



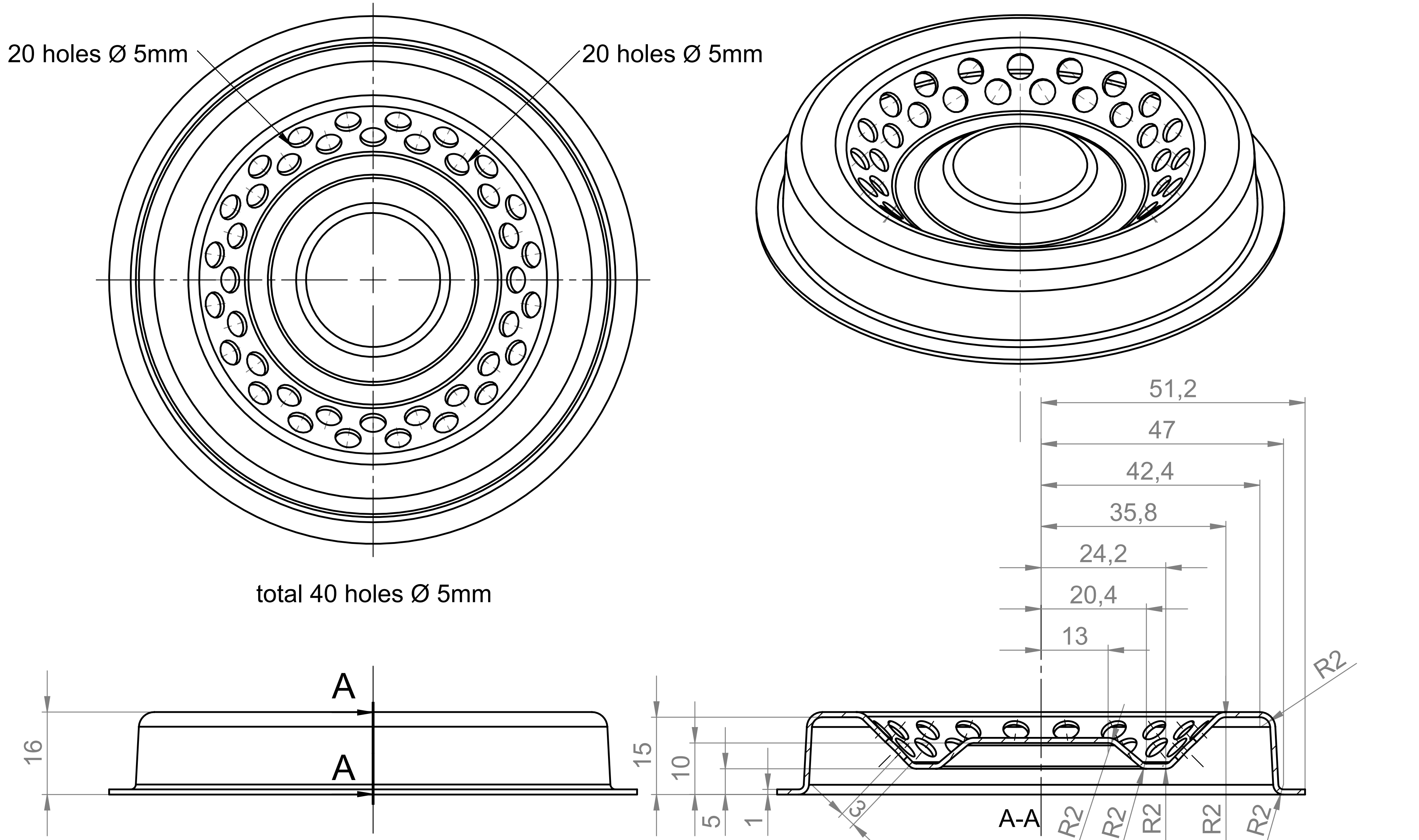


Welded/ connected



A-A

TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_burner_ASSEM	datum 29-11-2015 getekend <<(achter)namen & studienummers>>	groep <<dagdeel>>	schaal 1:1 formaat A4	maateenheid mm gewicht gram tekening nr. / opmerkingen <<tekeningnummer>>



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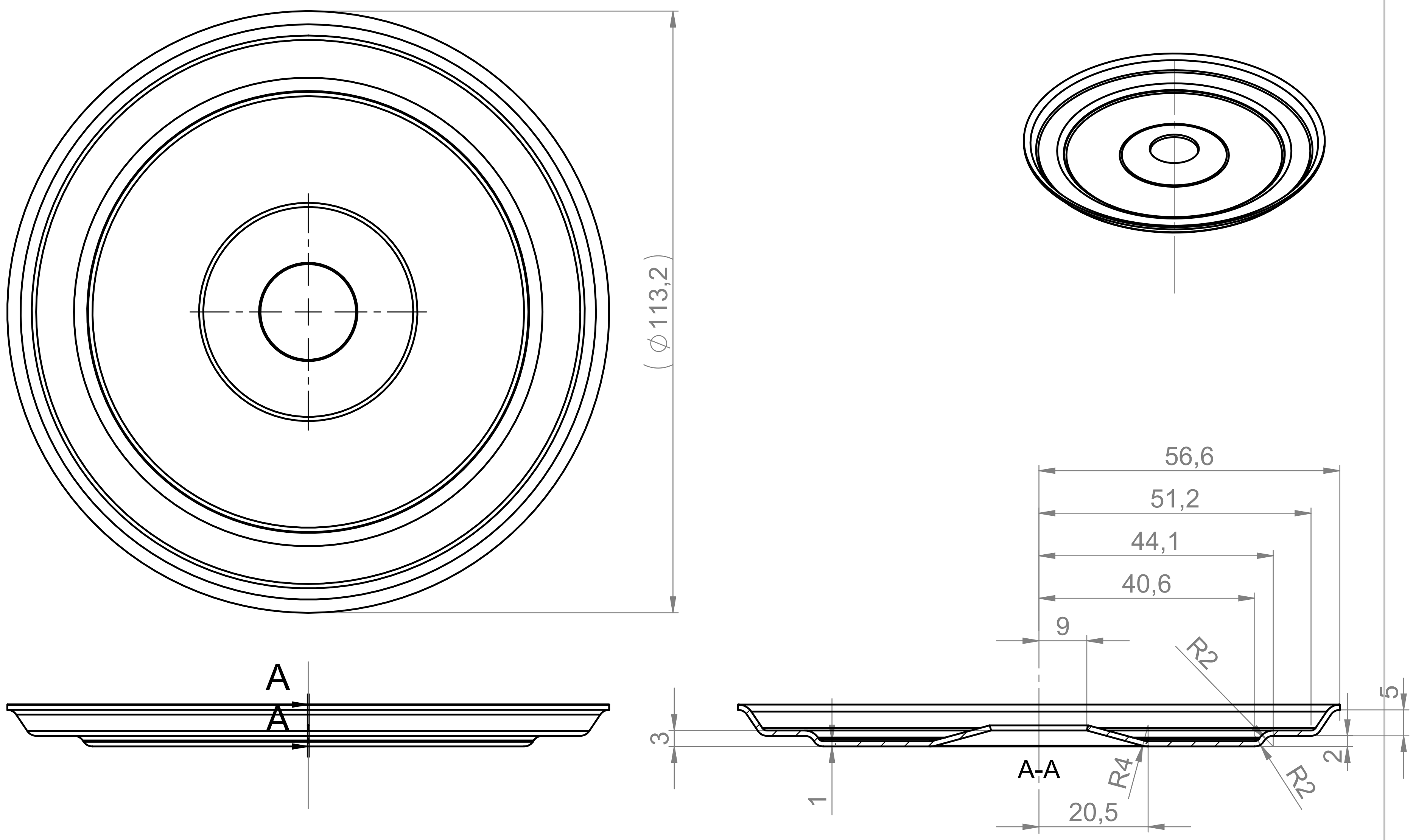

TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_burner_middle _PART_00	datum 29-11-2015		schaal 1:1	maateenheid mm
		getekend	groep <<dagdeel>>	formaat	gewicht gram
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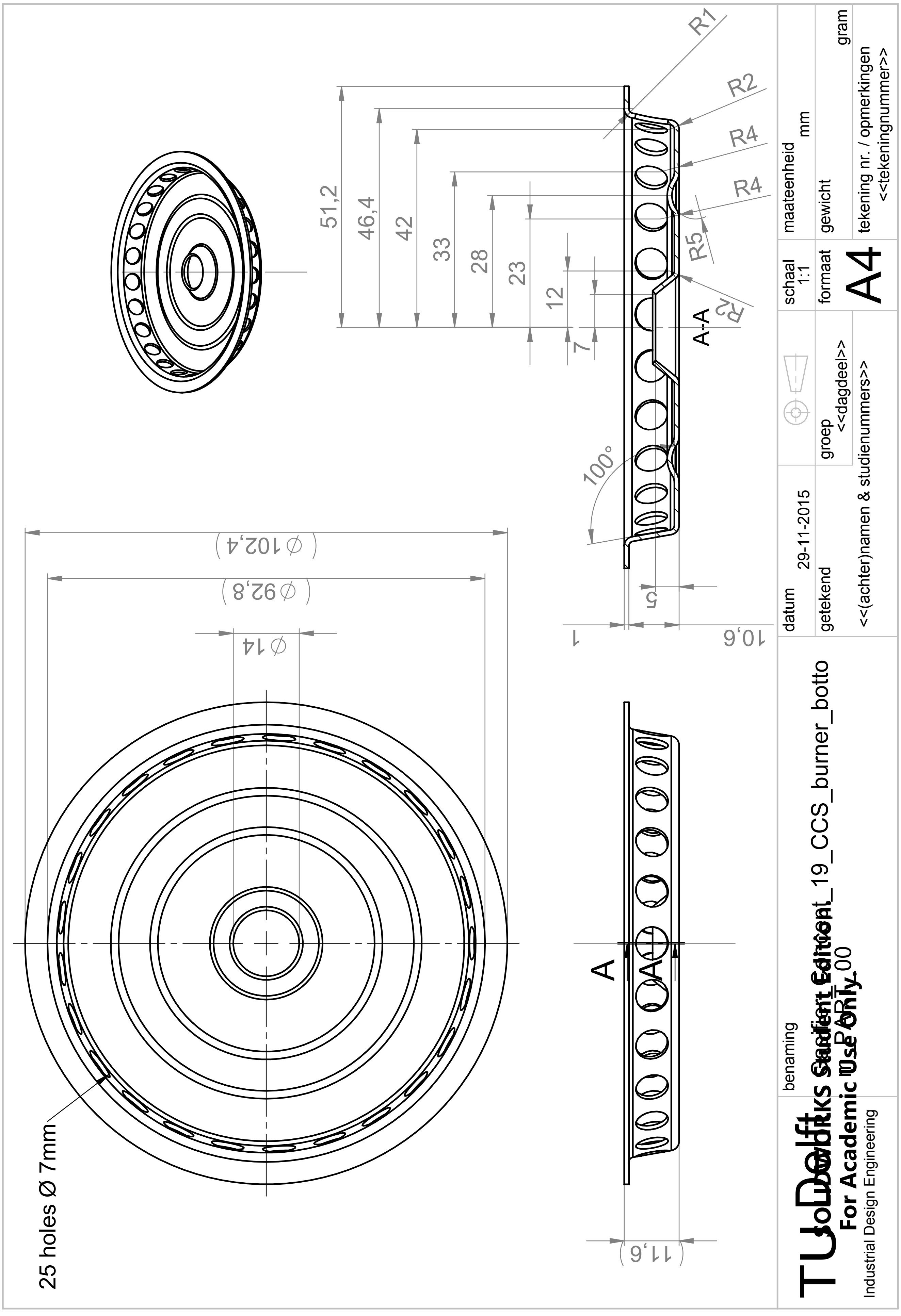

25 holes Ø 7mm
A
A
A-A
Ø102,4
Ø92,8
Ø14
11,6
10,6
1
5
100°
51,2
46,4
42
33
28
23
12
7
R1
R2
R4
R4
R5
R2
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benaming
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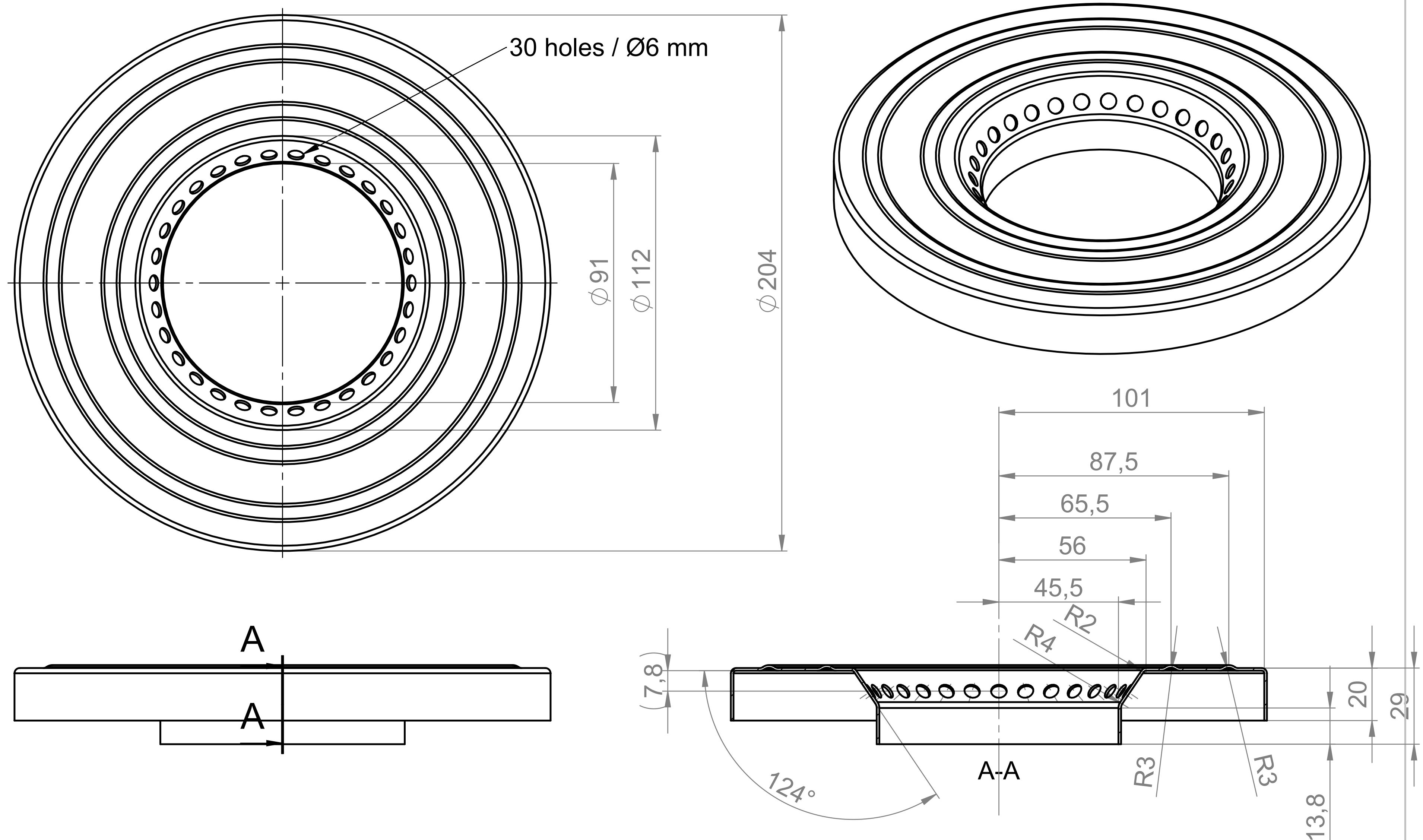
19_CCS_burner_botto
PART_00
datum
29-11-2015
getekend
<<(achter)namen & studienummers>>
groep
<<dagdeel>>
schaal
1:1
formaat
A4
maateenheid
mm
gewicht
gram
tekening nr. / opmerkingen
<<tekeningnummer>>



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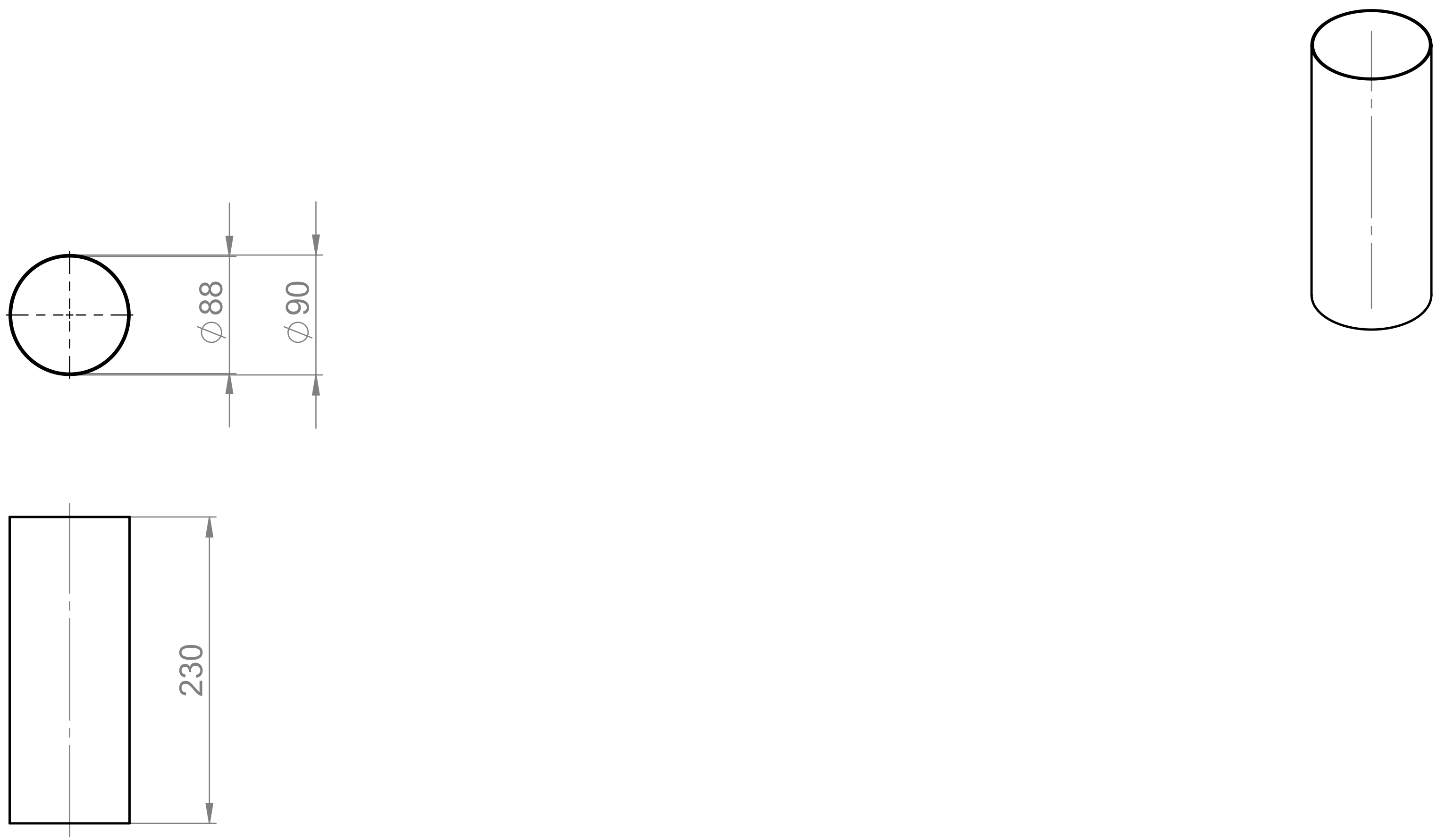

TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_Tube_reactor PART_00	datum 29-11-2015		schaal 1:5	maateenheid mm
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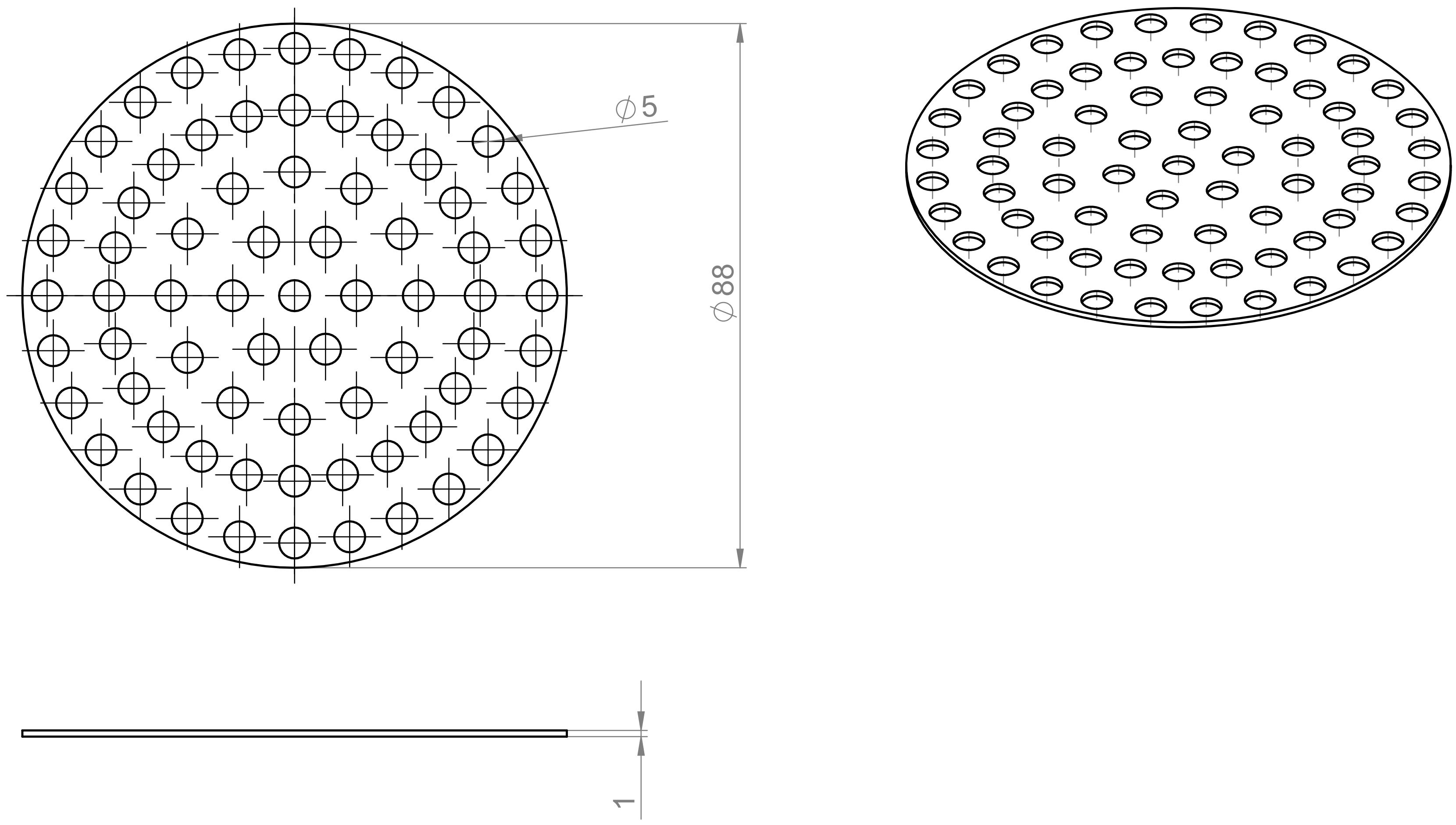

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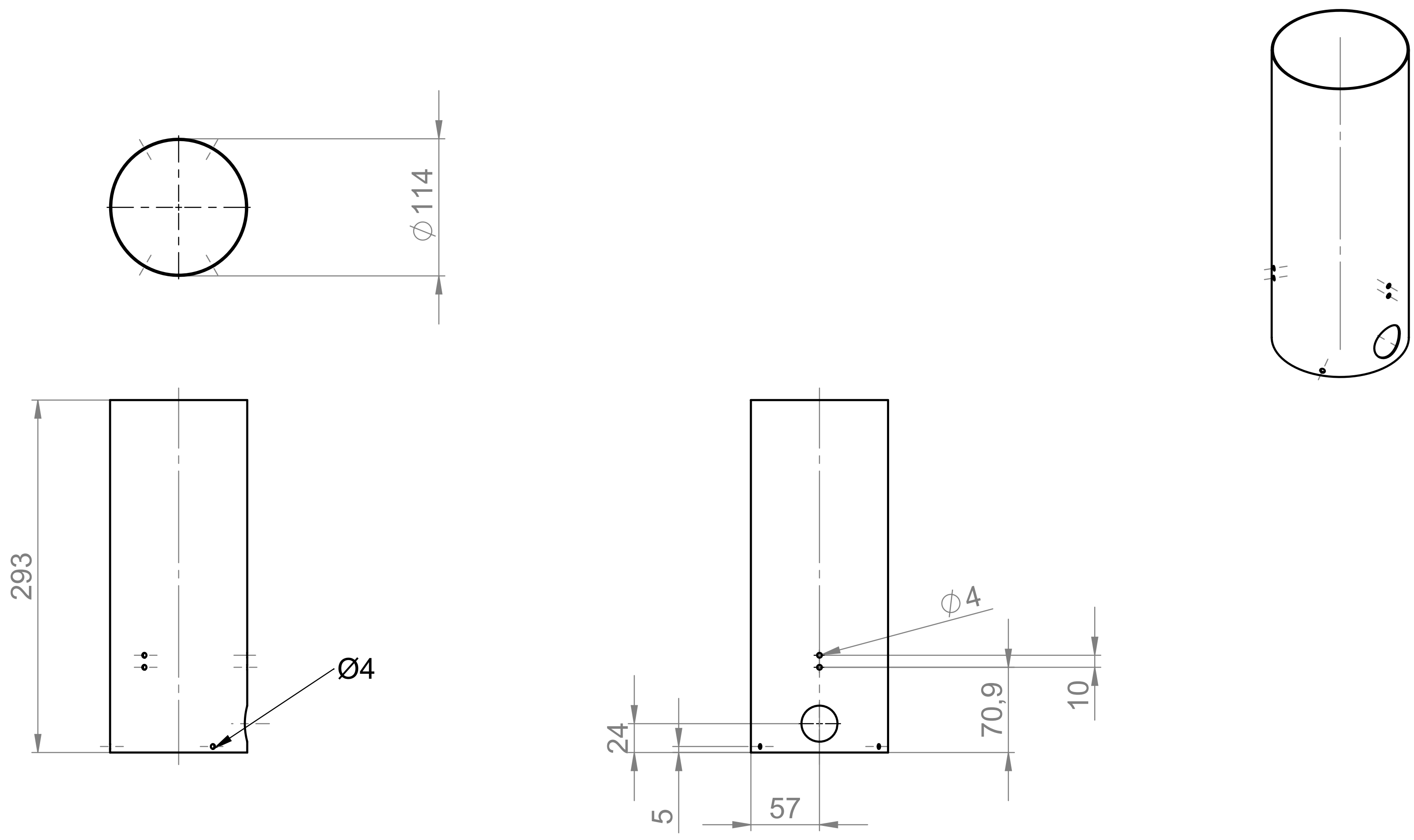
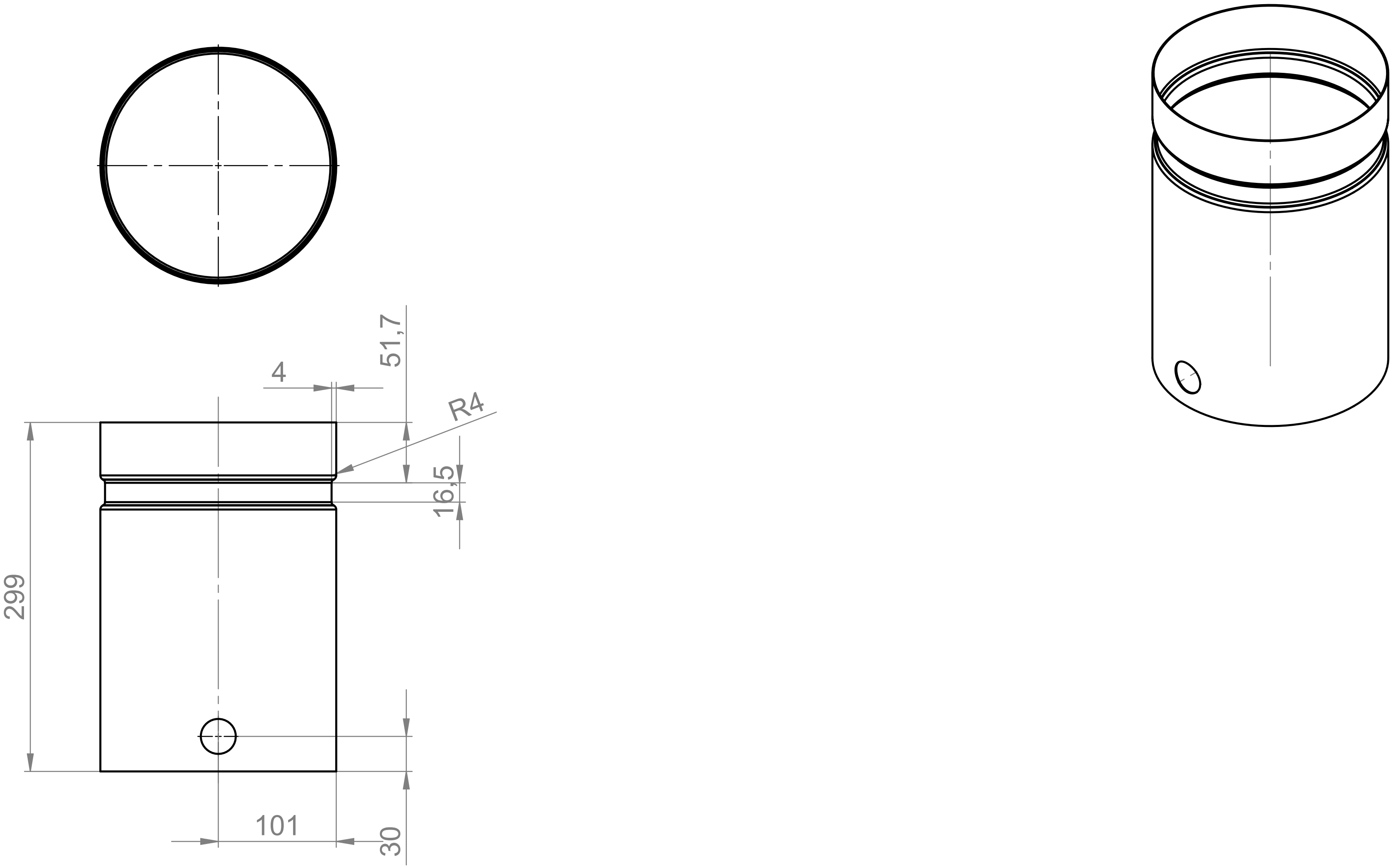


TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_Tube_inner_PART_00	datum 29-11-2015 getekend	groep <<dagdeel>>	schaal 1:5 formaat A4
		<<(achter)namen & studienummers>>		maateenheid mm gewicht gram tekening nr. / opmerkingen <<tekeningnummer>>



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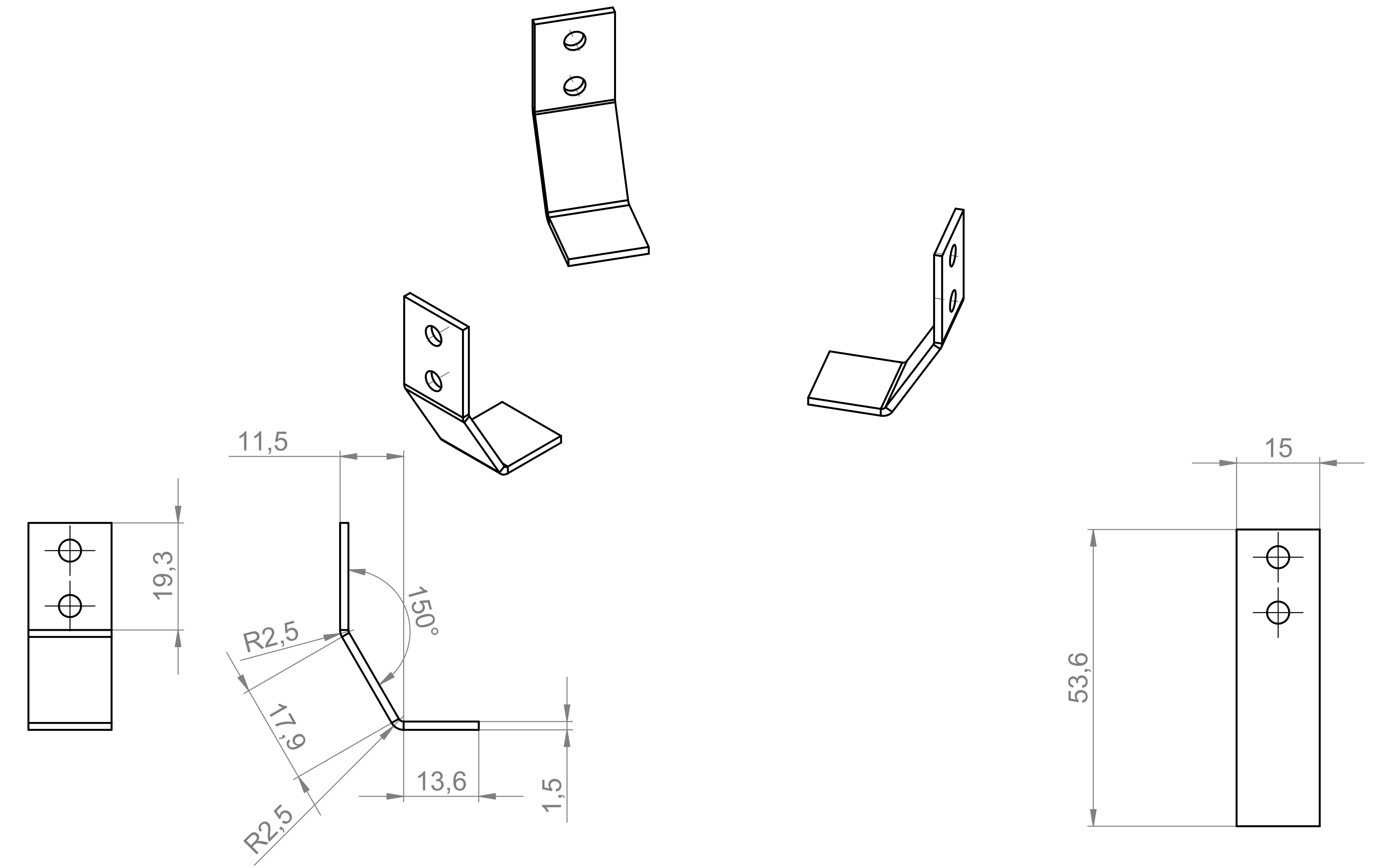

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benaming Gasifier_Component_19_CCS_Support_reactor_PART_00	datum 29-11-2015		schaal 1:1	maateenheid mm
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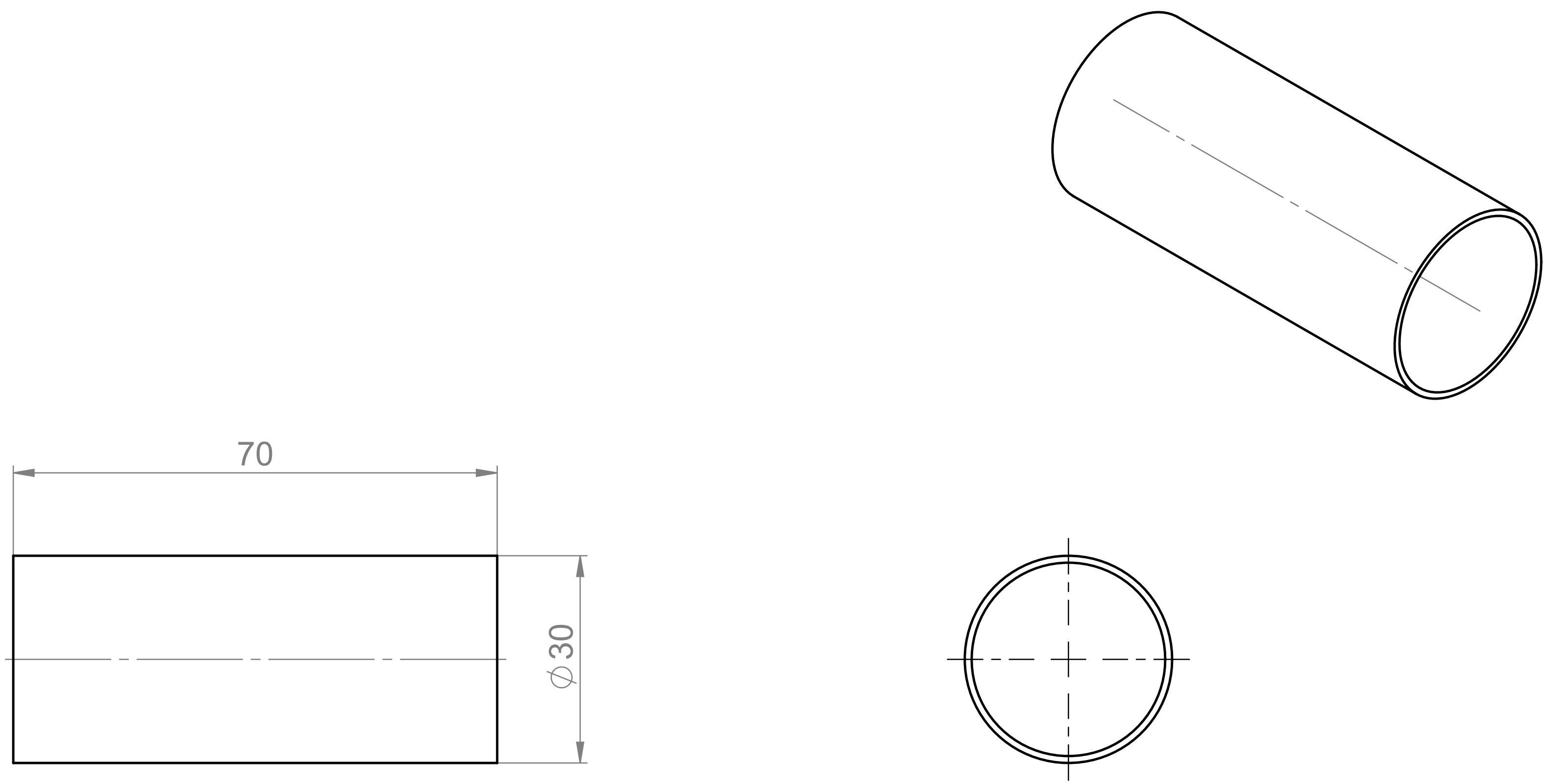
	<<(achter)namen & studienummers>>			tekening nr. / opmerkingen <<tekeningnummer>>



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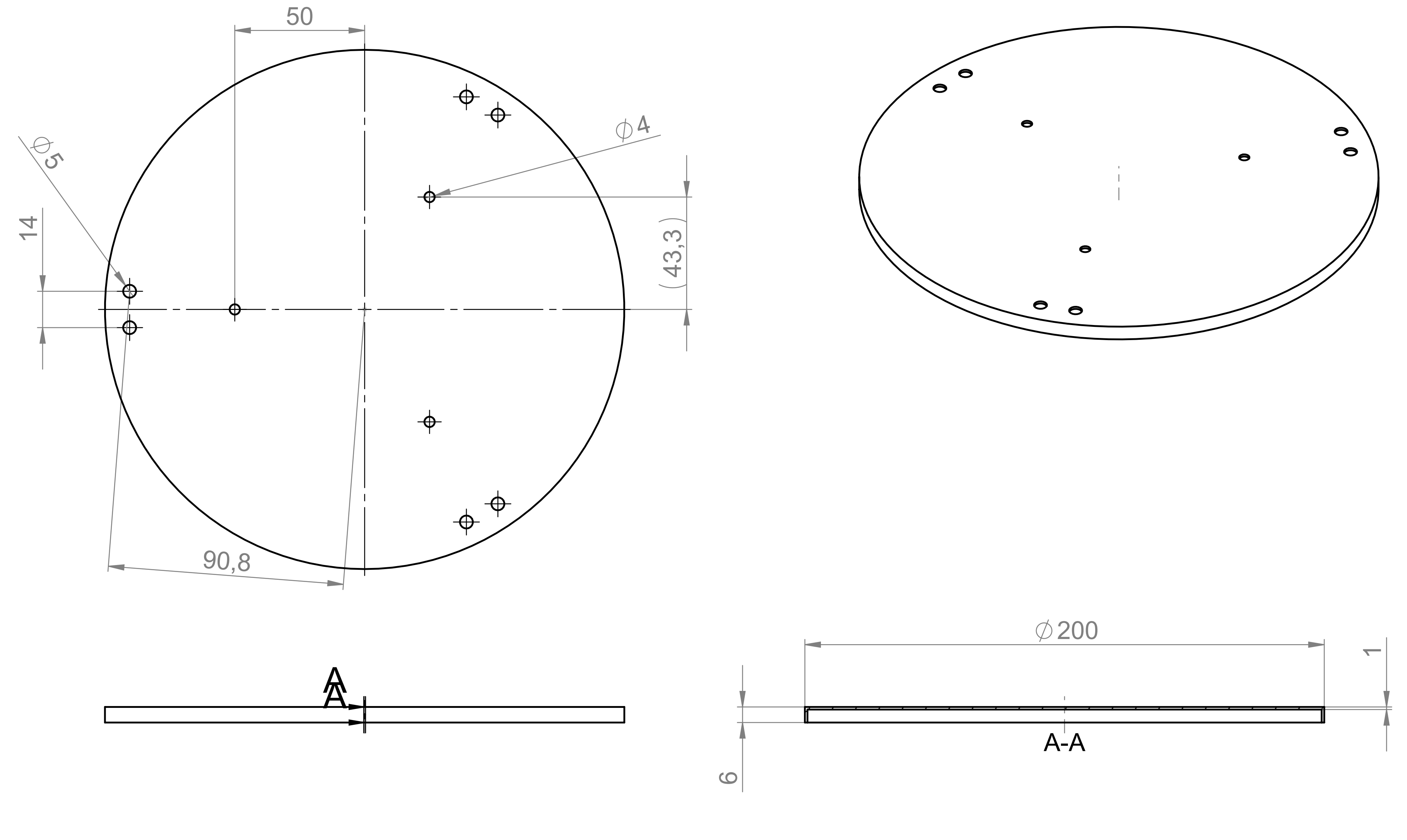
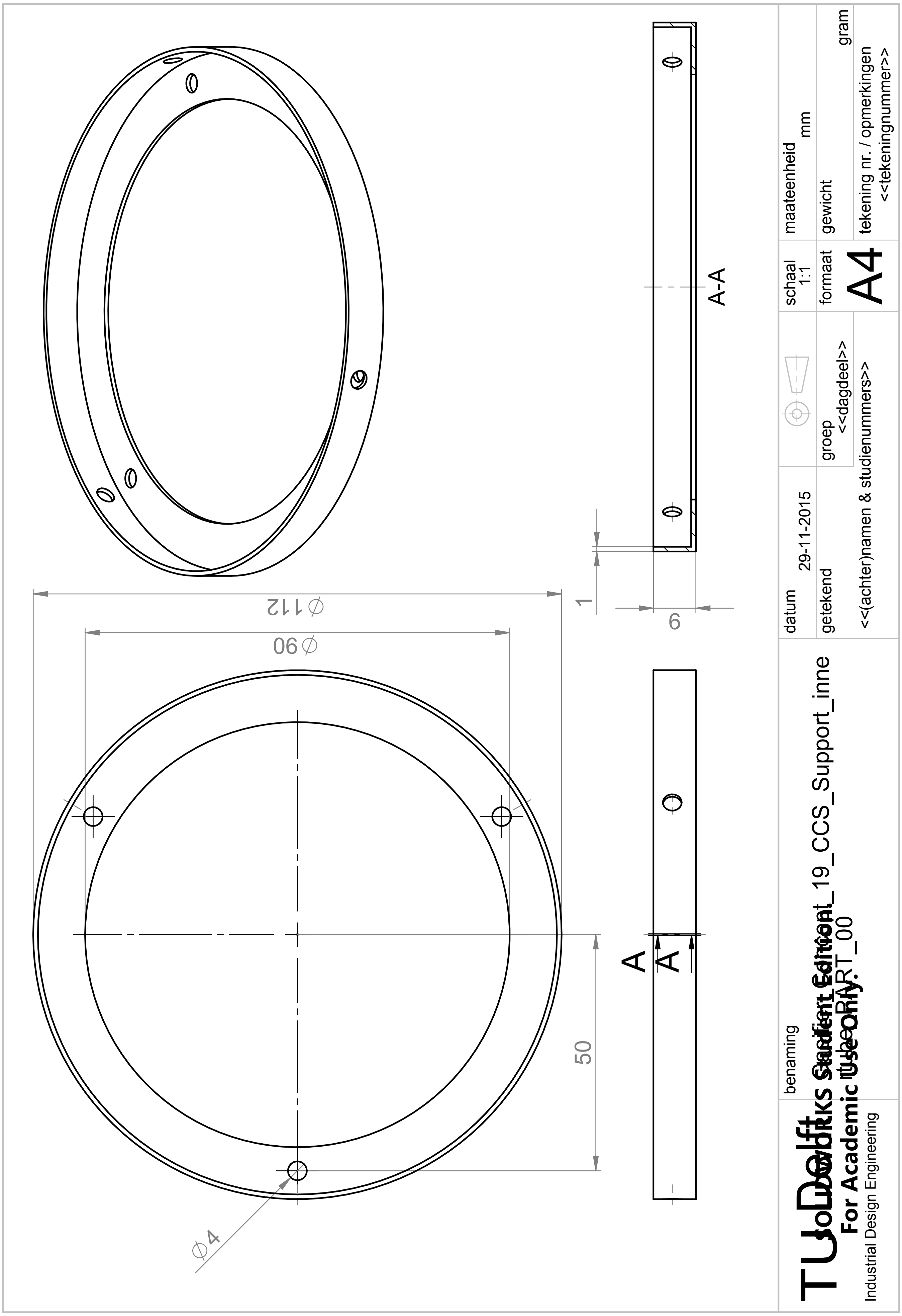
		getekend	groep <<dagdeel>>	formaat A4	gewicht gram
		<<(achter)namen & studienummers>>			tekening nr. / opmerkingen <<tekeningnummer>>



TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_plate_bottom PART_00	datum 29-11-2015		schaal 1:2	maateenheid mm
		getekend	groep <<dagdeel>>	formaat A4	gewicht gram
		<<(achter)namen & studienummers>>			tekening nr. / opmerkingen <<tekeningnummer>>



⌀112
⌀90
50
⌀4
A
A
A-A
1
6
TU Delft
Industrial Design Engineering
benaming
Support_19_CCS_Support_inne
tube
PART_00
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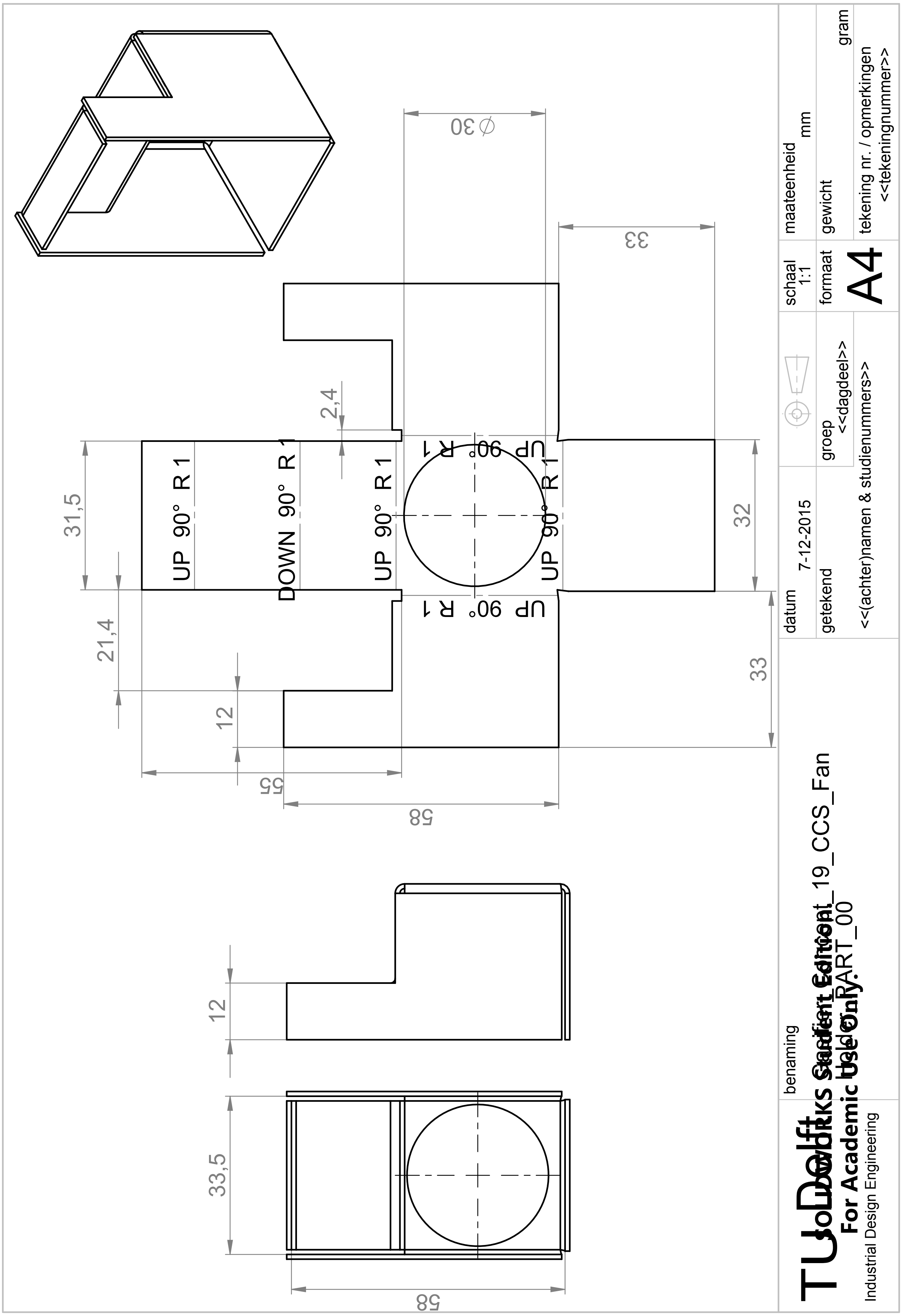
datum
29-11-2015
getekend
groep
<<dagdeel>>
<<(achter)namen & studienummers>>
schaal
1:1
formaat
A4
maateenheid
mm
gewicht
gram
tekening nr. / opmerkingen
<<tekeningnummer>>


UP 90° R 1
DOWN 90° R 1
UP 90° R 1
UP 90° R 1
UP 90° R 1
UP 90° R 1
∅30
33
31,5
2,4
21,4
12
55
58
32
33
12
33,5
58
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Industrial Design Engineering
benaming
Sanford_19_CCS_Fan holder_PART_00
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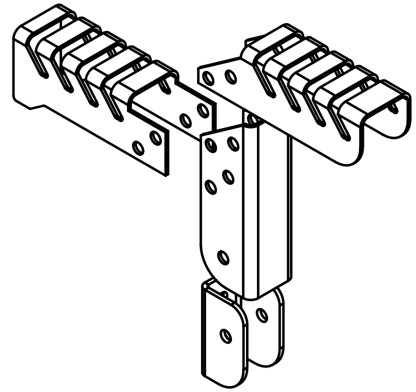
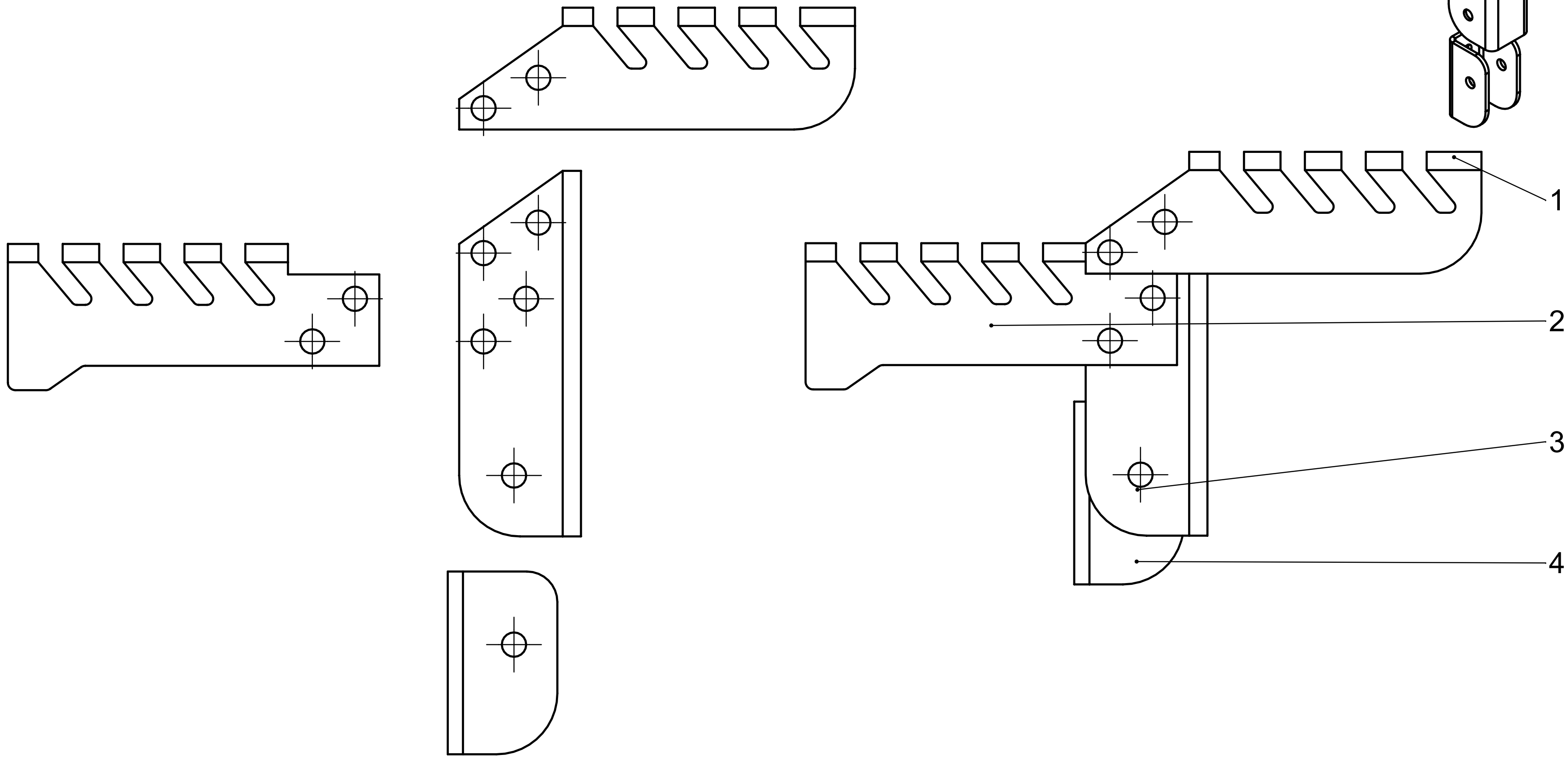
datum 7-12-2015
getekend
groep <<dagdeel>>
<<(achter)namen & studienummers>>
schaal 1:1
formaat A4
maateenheid mm
gewicht gram
tekening nr. / opmerkingen
<<tekeningnummer>>

no	part name	qty	Mass
1	Gasifier_Concept_19_CCS_Pot Support_handle_single_PART_00	1	19.2
2	Gasifier_Concept_19_CCS_Pot Support_Inner_single_PART_00	1	19.8
3	Gasifier_Concept_19_CCS_Pot Support_vertical_single_PART_00	1	22.9
4	Gasifier_Concept_19_CCS_Pot Support_mount_Single_PART_00	1	15.9





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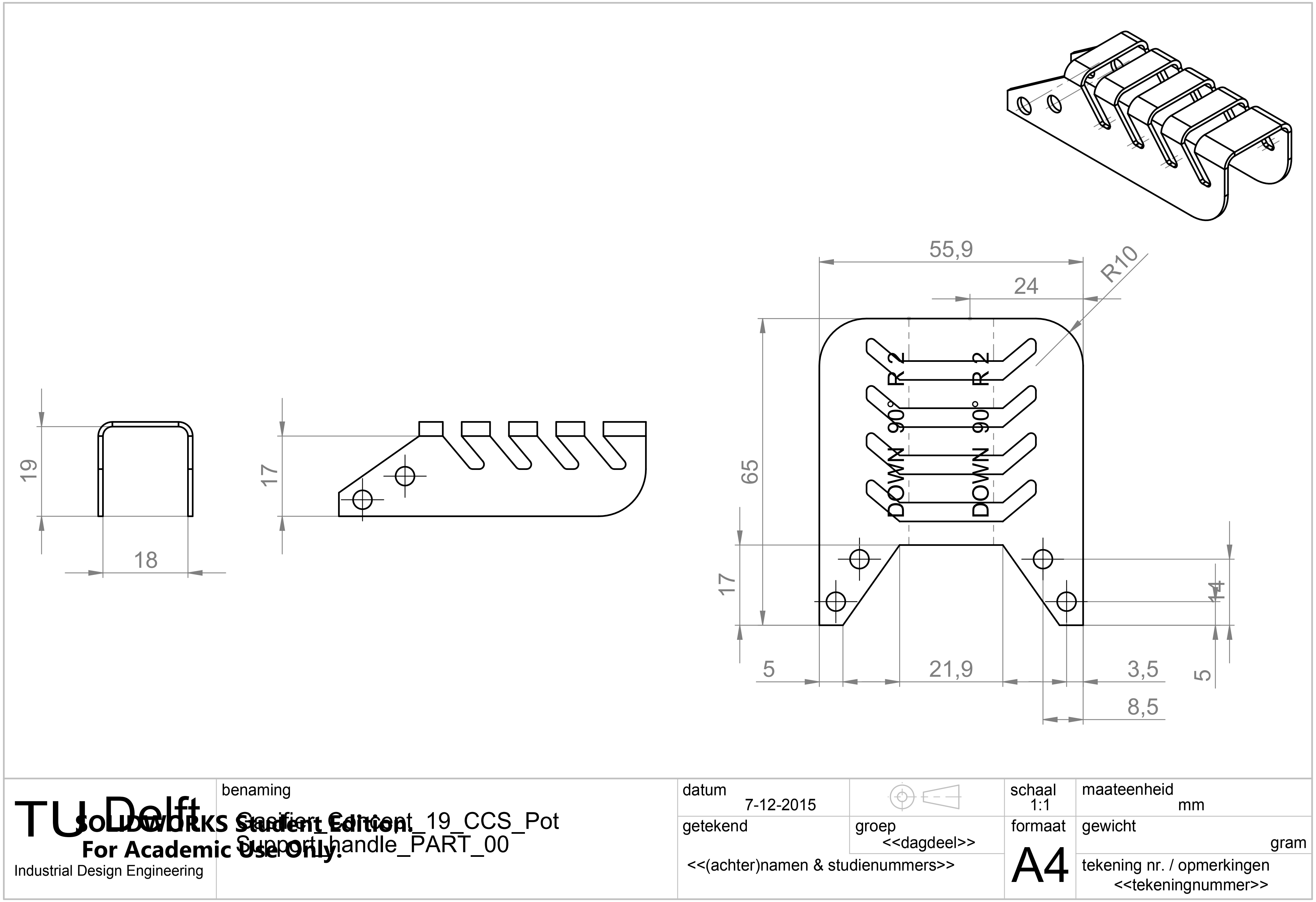
Industrial Design Engineering

benaming: Gasifier_Concept_19_CCS_Pot Support_Single_ASSEM_00	datum: 8-12-2015		schaal: 1:1	maateenheid: mm
	getekend	groep: <<dagdeel>>	formaat: A4	gewicht: gram
	<<(achter)namen & studienummers>>			tekening nr. / opmerkingen: <<tekeningnummer>>



19
18
17
65
17
5
21,9
55,9
24
R10
DOWN 90° R 2
DOWN 90° R 2
3,5
8,5
14
5
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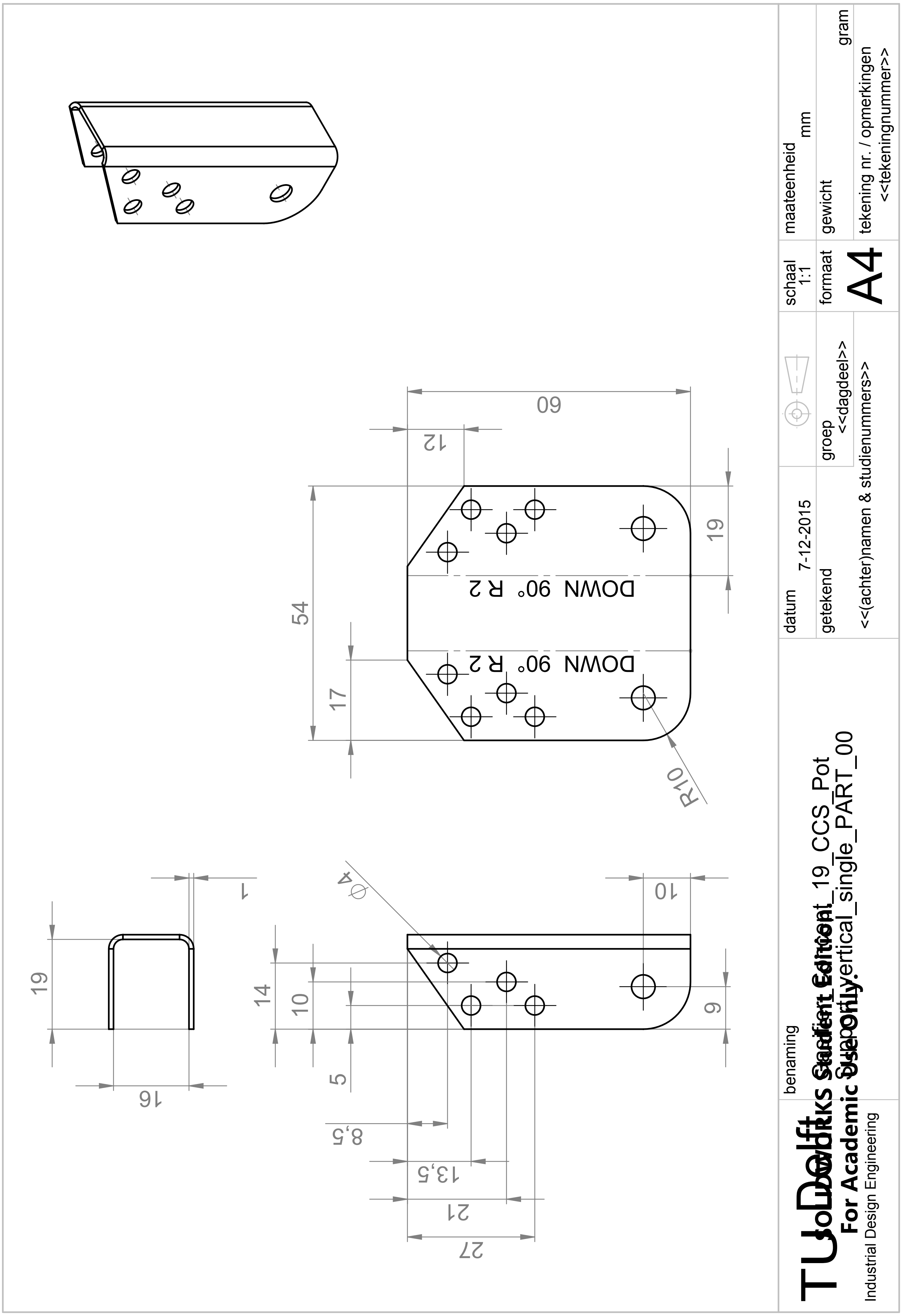
benaming
Gasifier_Concept_19_CCS_Pot
Support handle_PART_00
datum
7-12-2015
getekend
groep
<<dagdeel>>
<<(achter)namen & studienummers>>
schaal
1:1
formaat
A4
maateenheid
mm
gewicht
gram
tekening nr. / opmerkingen
<<tekeningnummer>>



60
12
19
54
17
DOWN 90° R 2
DOWN 90° R 2
R10
⌀4
10
1
19
16
14
10
5
9
8,5
13,5
21
27
benaming
Support_vertical_single_PART_00
19_CCS_Pot
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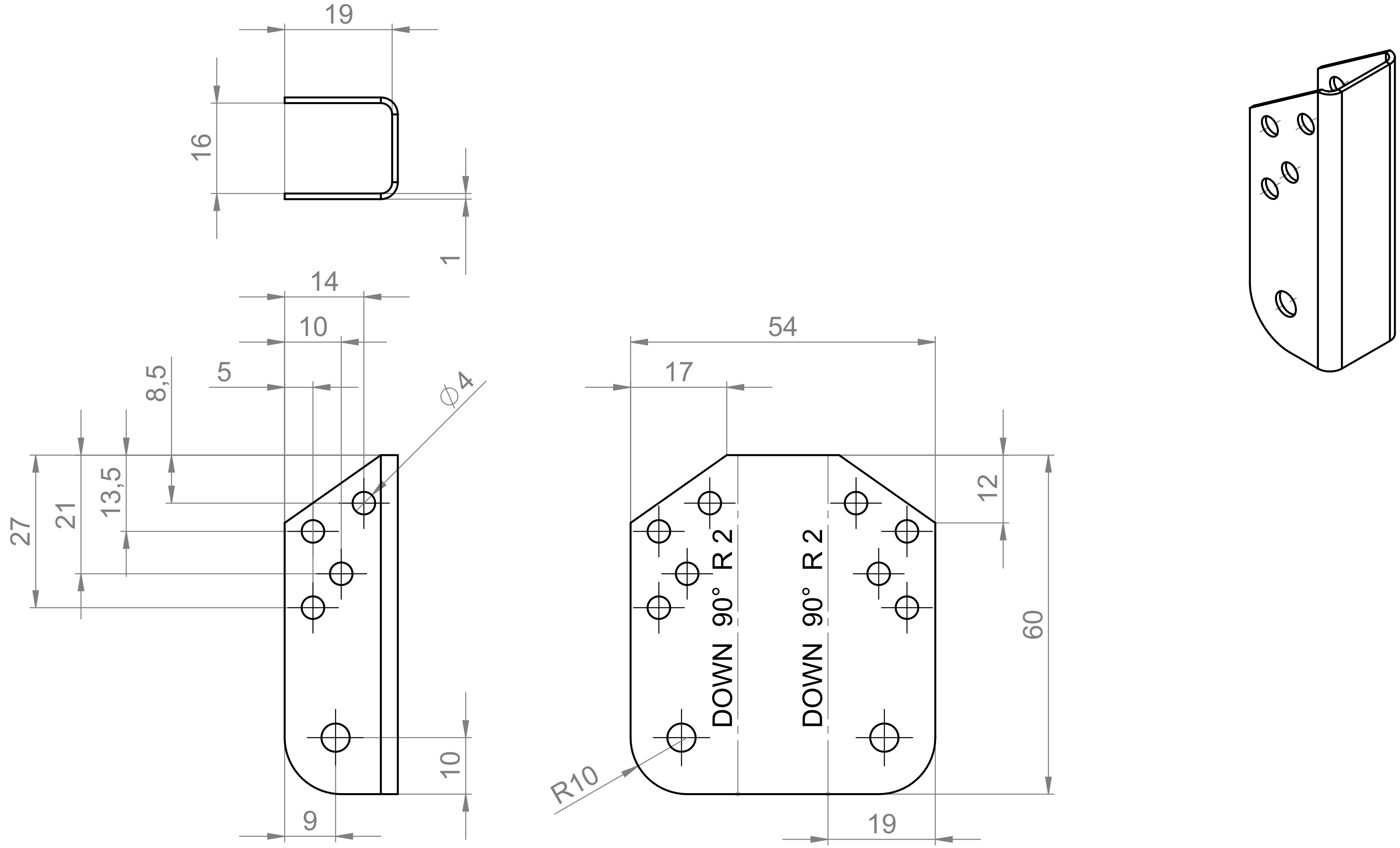
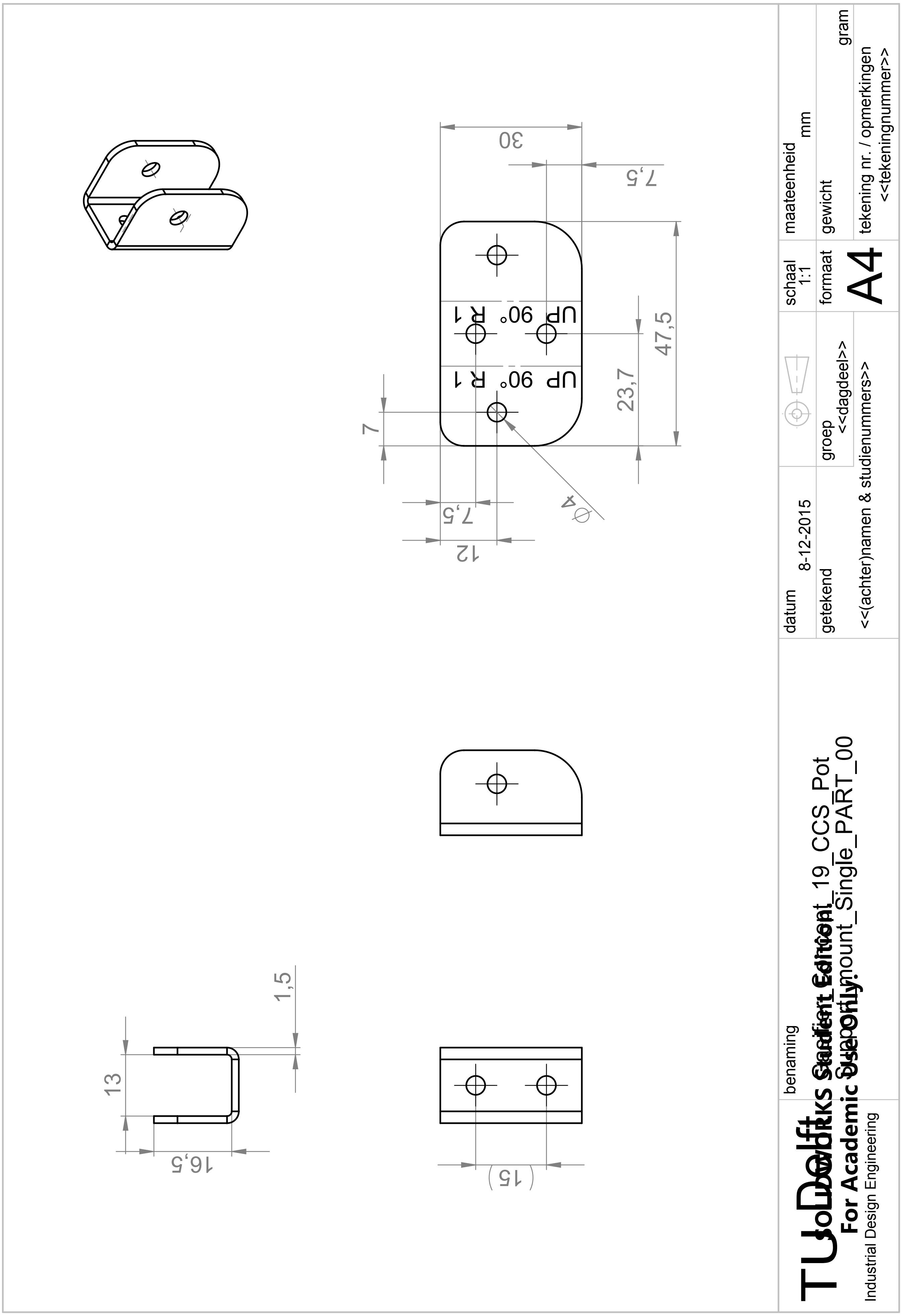
Industrial Design Engineering
datum
7-12-2015
getekend
<<(achter)namen & studienummers>>
groep
<<dagdeel>>
schaal
1:1
formaat
A4
maateenheid
mm
gewicht
gram
tekening nr. / opmerkingen
<<tekeningnummer>>



TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_Pot Support_vertical_single_PART_00	datum 7-12-2015 getekend <<(achter)namen & studienummers>>	groep <<dagdeel>>	schaal 1:1 formaat A4	maateenheid mm gewicht gram tekening nr. / opmerkingen <<tekeningnummer>>


30
7,5
47,5
23,7
7
7,5
12
∅4
UP 90° R 1
UP 90° R 1
13
16,5
1,5
(15)
benaming
Support_19_CCS_Pot
mount_Single_PART_00
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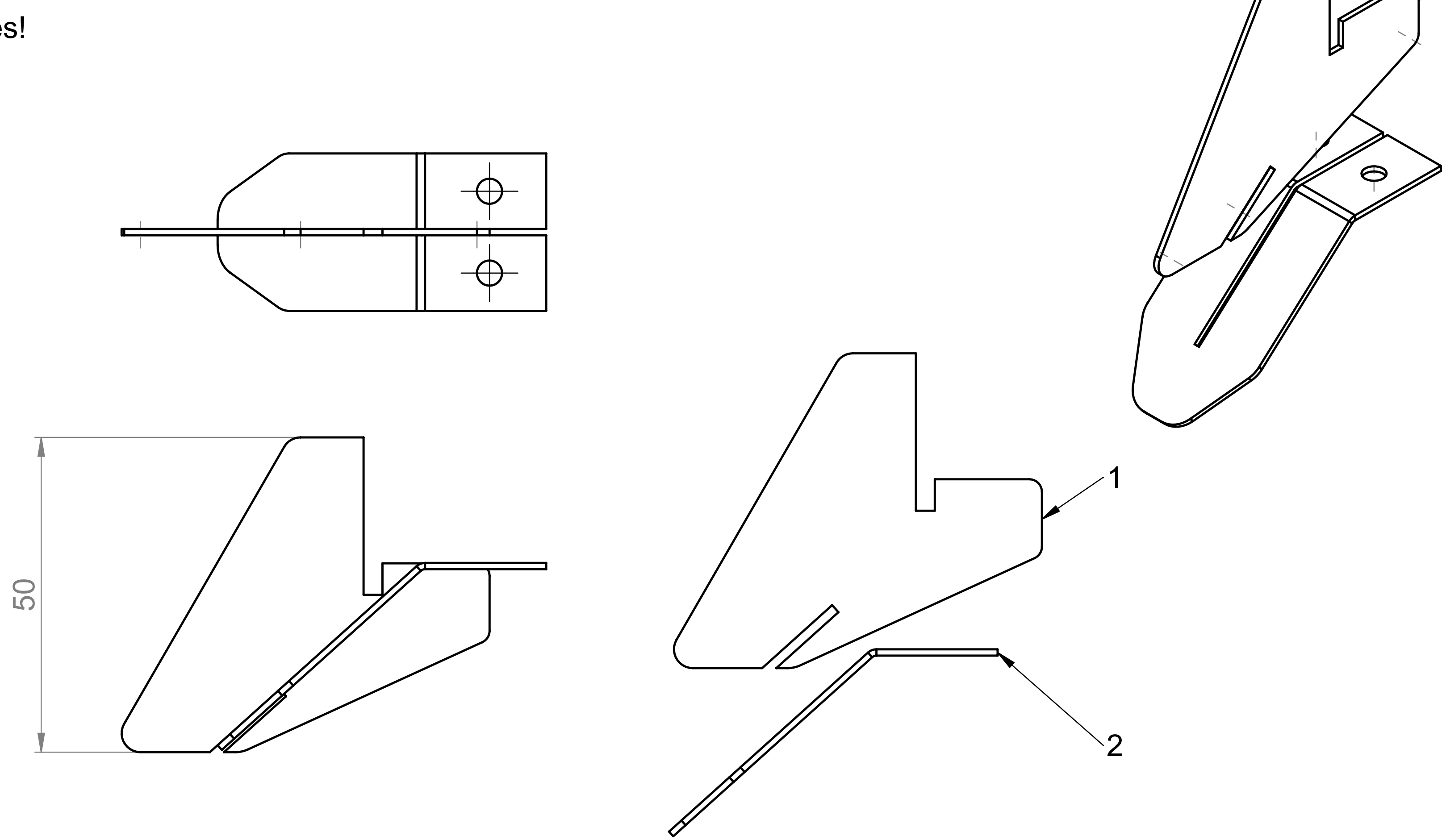
TU Delft
Industrial Design Engineering
datum
8-12-2015
getekend
groep
<<dagdeel>>
<<(achter)namen & studienummers>>
schaal
1:1
formaat
A4
maateenheid
mm
gewicht
gram
tekening nr. / opmerkingen
<<tekeningnummer>>

no	part name	qty
1	Gasifier_Concept_19_CCS_SheetMetal Feet_P1_PART_00	1
2	Gasifier_Concept_19_CCS_SheetMetal Feet_P2_PART_00	1

Produce 3 times!



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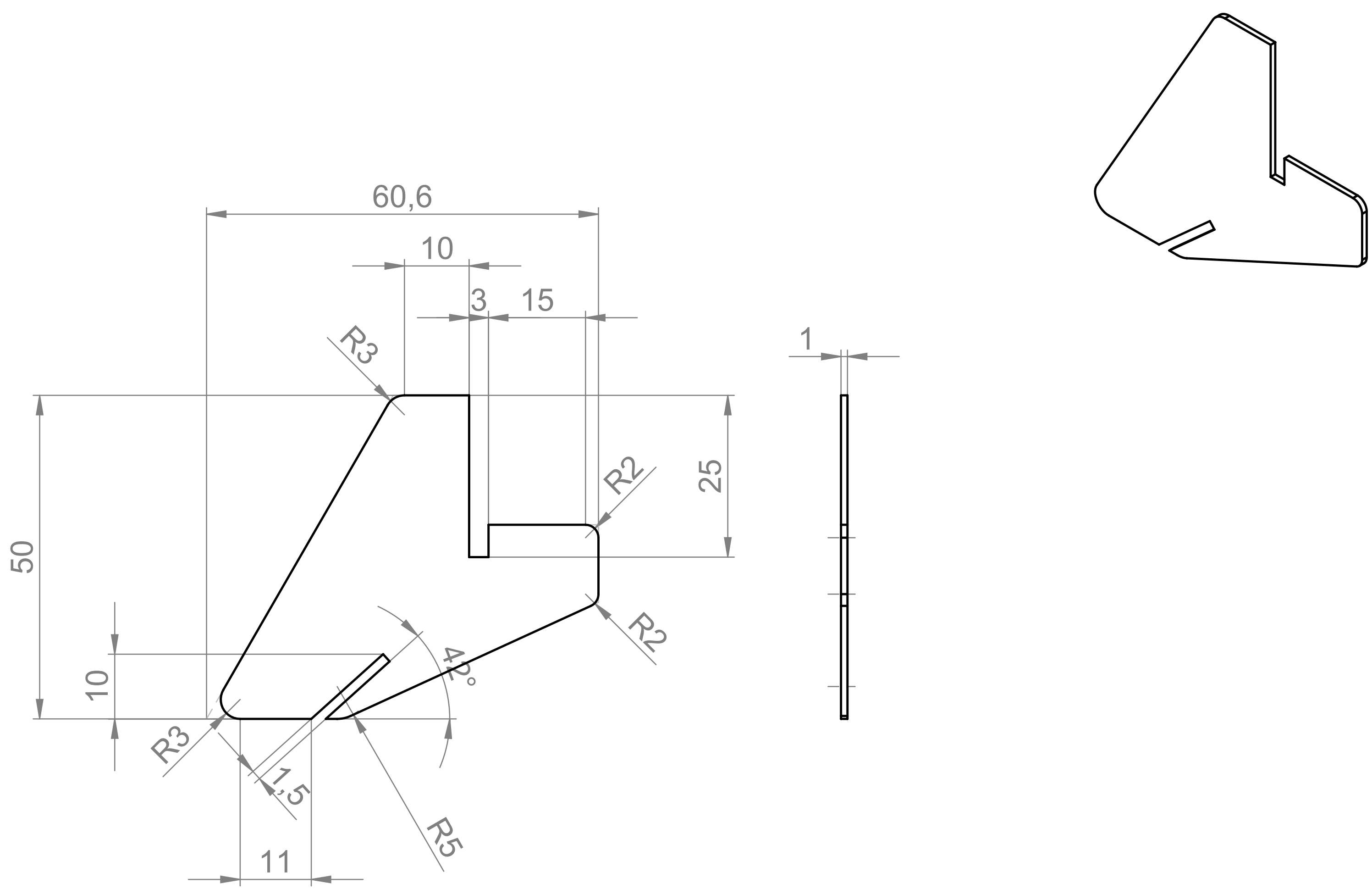
benaming: Gasifier_Concept_19_CCS_feet_Single_ASSEM_00	datum: 8-12-2015	schaal: 1:1	maateenheid: mm
	getekend	groep: <<dagdeel>>	formaat: A4	gewicht: gram
	<<(achter)namen & studienummers>>		tekening nr. / opmerkingen: <<tekeningnummer>>



TU Delft Industrial Design Engineering	benaming Gasifier_Concept_19_CCS_SheetMetal Feet_P1_PART_00	datum 7-12-2015		schaal 1:1	maateenheid mm
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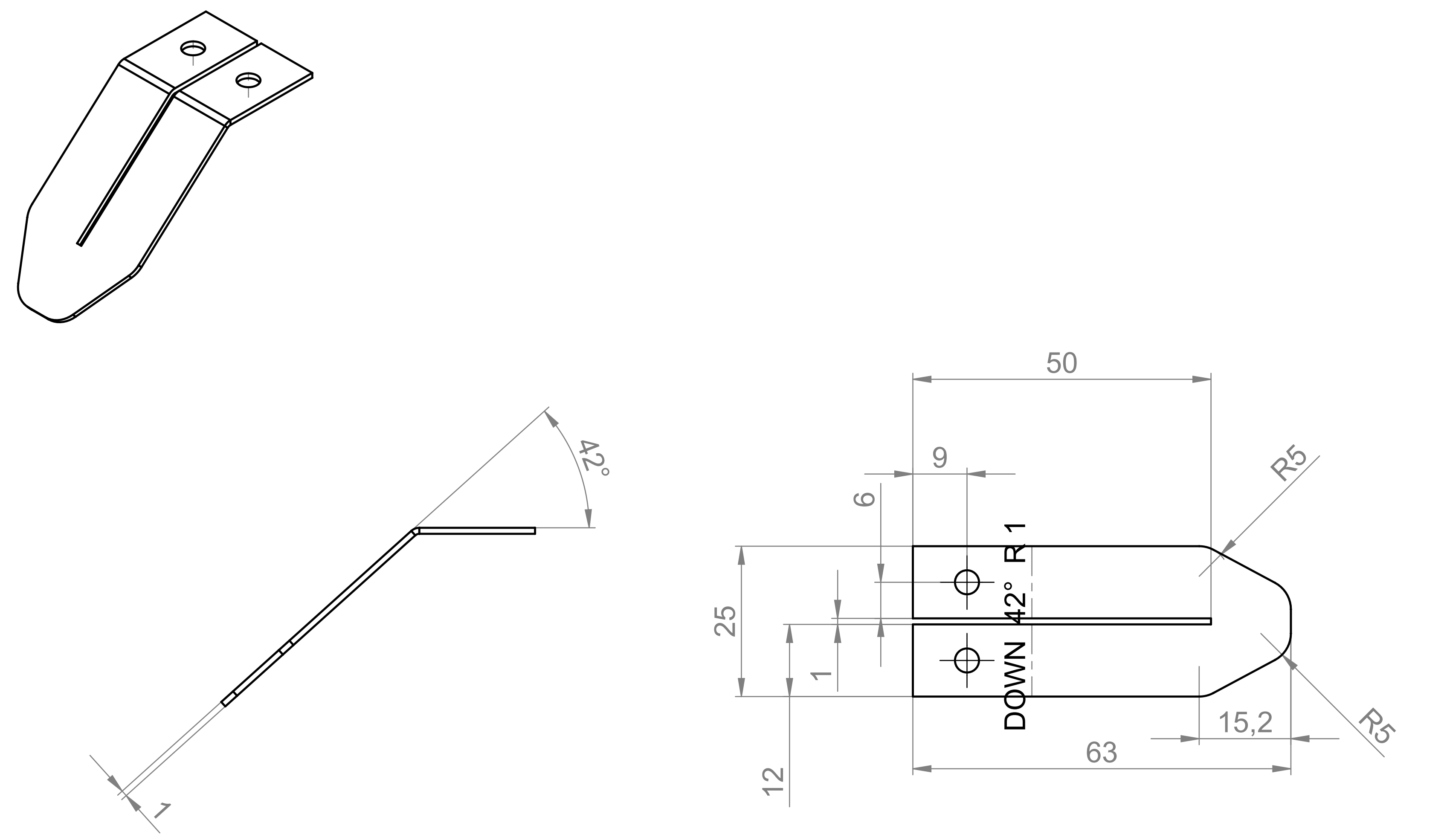

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		<<(achter)namen & studienummers>>			tekening nr. / opmerkingen <<tekeningnummer>>

APPENDIX I: WORKSHOP PRESENTATION

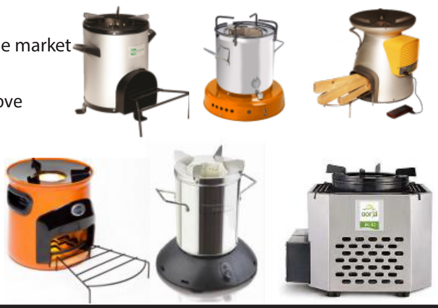
Market

- Market analysis
- Comparison to CCS gasifier

Market analysis

Popular models in the market

- Greenway smart stove
- Ace 1 cookstove
- Biolite homestove
- Envirofit g3300
- Philips HD4012
- Oorja pellet stove



Benchmarking

Model	Price	Boiling 2 liter	Specific fuel consumption g fuel/kg food*
Greenway smartstove	$22.5	15 min	-
Ace 1 cookstove	$150**	N.A.	83.0
Biolite homestove	$50***	27:30 min	114
Envirofit g3300	$120	17 min	143
Philips HD4012	$130	7:30 min	132.3
Oorja pellet stove	$23	N.A.	89.3
CCS gasifier	$<20	5:25 min	
Open fire	-		295

*Different types of food, results are not scientific and should be explored further for better comparison.
** Give away or paid with micro financing structure in developing countries.
*** only for developing countries.

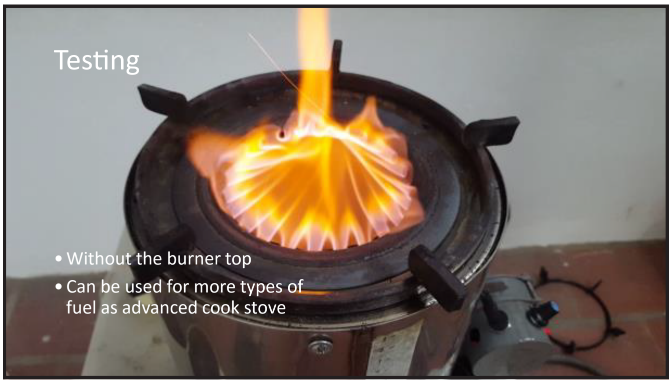
Usability testing

Drivinga car in "first" gear only

- Not efficient by improper usage of the stove.
- Too much fuel is put into the fuel chamber also during the gasification.
- Stoves consumed unreasonable amounts of fuel, emitted considerable amounts of smoke, and cooking time was not reduced.

Testing

- Flame stability
- Boiling water test
- Surface heat
- Concept comparison



Semi gasification

- Using the gasifier as an advance cook-stove.
- Well know principle like the Philips stove and Ace one stove.

Design

- Modular approach
- Personal styling
- Cooking equipment

Modular part design

- Burner is manufactured from 3 stamped pressed parts
- Primary and secondary airflow are mixed by negative pressure differences

Personal design

- Different colours to match your personal style.

Personal design

- User research will determine the available colours

Pot support

- The pot support is designed to offer the best performance for different sizes (36 cm pot)
- Arms can be folded back to increase height if desired.

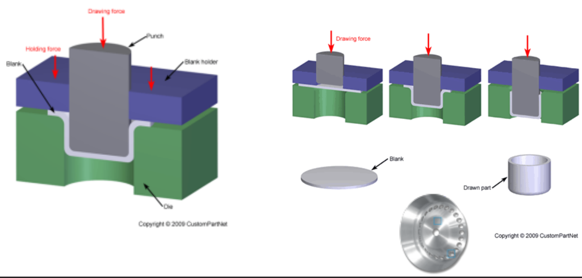
Pot support

- When collapsed down the pot support presses down on the burner improving the insulation.

Future steps

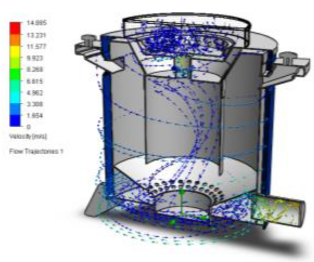
- Design for manufacturing
- Improved concept designs
  - Continues gasifier

Design for manufacturing: Deep drawing



Continues feed innovation

- Air flow simulation
- Optimization of the airflow is crucial for the performance

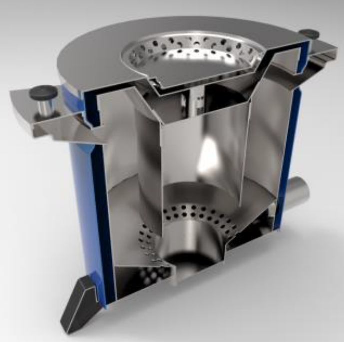


Fuelling design

- Focus on usability for longer cooking needs

Detailed view

- Secondary air cools the outer surface.
- Pellets are preheated, vaporizing the moisture



APPENDIX I.2: WORKSHOP PRESENTATION PICTURES


A Rice Husk Gasification-Stove for rural Vietnam


Personal design
User research will determine the available colours

APPENDIX J: TESTING REPORT

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1 INTRODUCTION

A new prototype of the CCS gasifier has been developed by CCS and Delft University of Technology (TUD) in the Netherlands. The stove was tested following the WBT 4.2.3 protocol. Three tests were executed in order to determine how efficient the stove uses fuel to heat water in a cooking pot and the quantity of emissions produced while cooking. The test describes three phases; a cold-, hot- and simmer -phase. For this test each phase uses a pot which is filled with 2.5-liter water and starts with 450 grams of fuel.

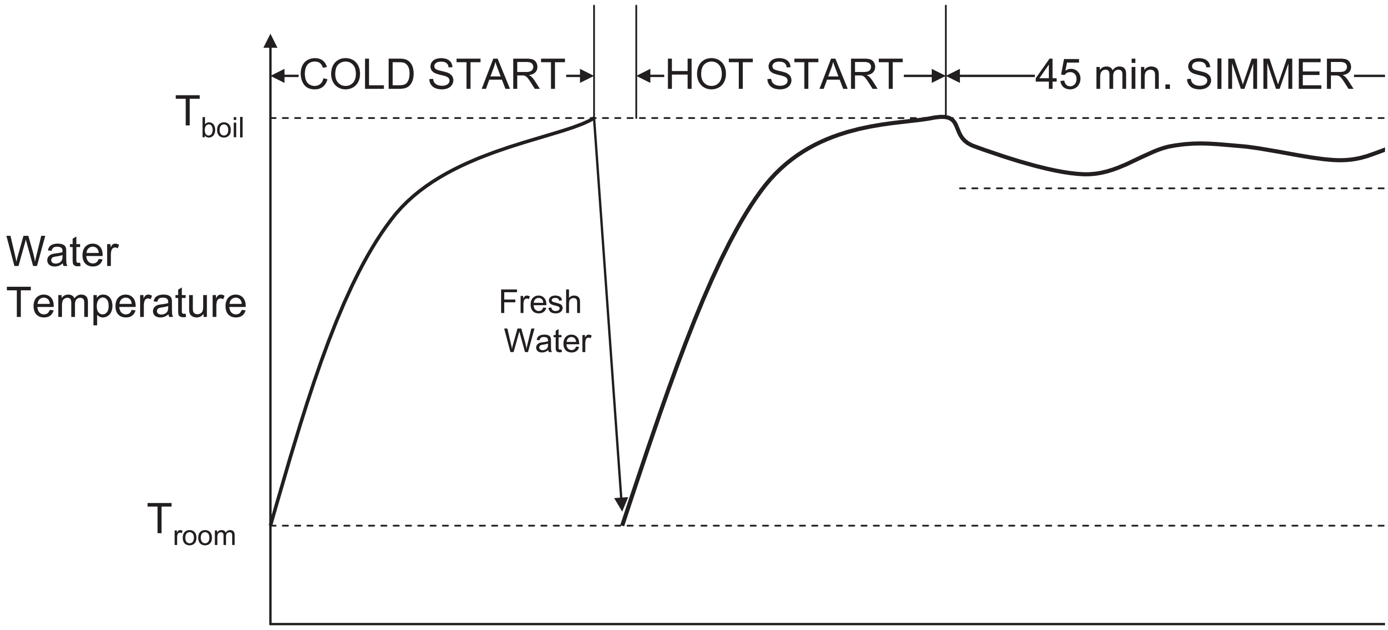


Image 1: Water Boiling test procedure

1. For the ***cold-start high-power phase***, the tester begins with the stove at room temperature and uses 450 g of fuel from a pre-weighed bundle to boil a measured quantity of 2.5 liters of water in a standard pot. The tester then replaces the boiled water with a fresh pot of ambient-temperature water to perform the second phase. Time to boil, and weight of the pot with water and fuel should be recorded and measured before and after each test.
2. The ***hot-start high-power phase*** is conducted after the first phase while stove is still hot. Again, the tester uses 450 g fuel from a pre-weighed bundle to boil a measured quantity of 2.5 liters of water in a standard pot. Repeating the test with a hot stove helps to identify differences in performance between a stove when it is cold and when it is hot. This is particularly important for stoves with high thermal mass.
3. The ***simmer phase*** provides the amount of fuel required to simmer a measured amount of water at a temperature just below boiling point for 45 minutes. This step simulates the long cooking of legumes or pulses common throughout of the world.

2 STOVE DESCRIPTION

The CCS gasifier stove is a prototype aimed to optimize the performance of micro gasification. The stove is based on the Top Lid-Updraft (TLUD) principle, and has a batch operation. The stove is optimized for wood pellet gasification.

The burner is improved using iterative testing and airflow simulations. It enables mixing of the primary and secondary air flow resulting in a cleaner combustion.

The produced gas is burned on top of the burner close to the pot decreasing thermal energy loss to the environment.

Image 2: CCS micro-gasifier cookstove during operation

2.1 Pollutant emissions measured

The WBT recommends that CO_2, CO and PM2.5 are measured during the test. For this test a PM2.5 and CO measuring device was available. It should be noted that levels of pollutant exposure to humans and room emissions concentrations were not measured. Rather, total pollutant concentrations were measured in real time. The following points discuss the significance of the emission values measured.

- **CO** (carbon monoxide) is a primarily formed as the product of partial oxidation of carbon ($C + ½ O_2 \rightarrow CO$). The presence of CO in the products from a combustion device indicates global or local incomplete combustion generally due to insufficient availability of oxygen. CO itself is a combustible gas ($2CO + O_2 \rightarrow 2CO_2$ + heat). However, in many combustion devices such as cookstoves, the concentration of CO in the exhaust gases is below the lower flammability limit of CO (12 vol%). CO is highly toxic because it combines with hemoglobin forming carboxyhemoglobin (COHb) and displacing sites where oxygen attaches to hemoglobin for transport to organs throughout the body. Chronic CO exposure is also believed to result in chronic ailments in the cardiovascular and nervous systems. The WHO recommended maximum exposure levels for CO are 30 ppm for one hour and 90 ppm for 15-minute time periods (WHO 2010).

- **PM** (particulate matter) can be introduced into air through several mechanisms including sediment entrainment and combustion of hydrocarbon fuels. Health risks associated with airborne PM are related to the particle size. Of particular concern are particles smaller than 10 micrometers (microns) in size, referred to as PM10, which are inhalable and can enter deep into the lungs and cardiovascular system, contributing to a variety of health problems including respiratory disease and asthma. Inefficient biomass cookstoves and open fires emit large amounts of PM10 and fine particulate (PM2.5) which, coupled with other household and ambient air pollutants, contribute to 7 million premature deaths per year worldwide (WHO 2014b). The WHO guideline for maximum exposure to ambient PM10 is 50 $\mu g/m^3$ (WHO 2005). In addition, fine particles commonly referred to as soot or black carbon (BC) are produced from incomplete combustion of carbonaceous fuels. BC emissions are a significant concern not only because of their adverse health effects when inhaled, but also because they become entrained in the atmosphere and are highly absorptive of solar radiation, about one million times more than carbon dioxide. Therefore, reducing BC emissions could have an immediate impact on climate change.

2.3 Testing objective

The goals of this study is to demonstrate quantified data regarding the efficiency, emissions, and other performance such as time-to-boil of the developed micro-gasifier stove.

3 MATERIALS

A testing environment had to be designed in order to perform the tests. It was chosen to perform the test in a chimney as this would provide natural air circulation and a funnel on which the emission measurement devices could be placed.

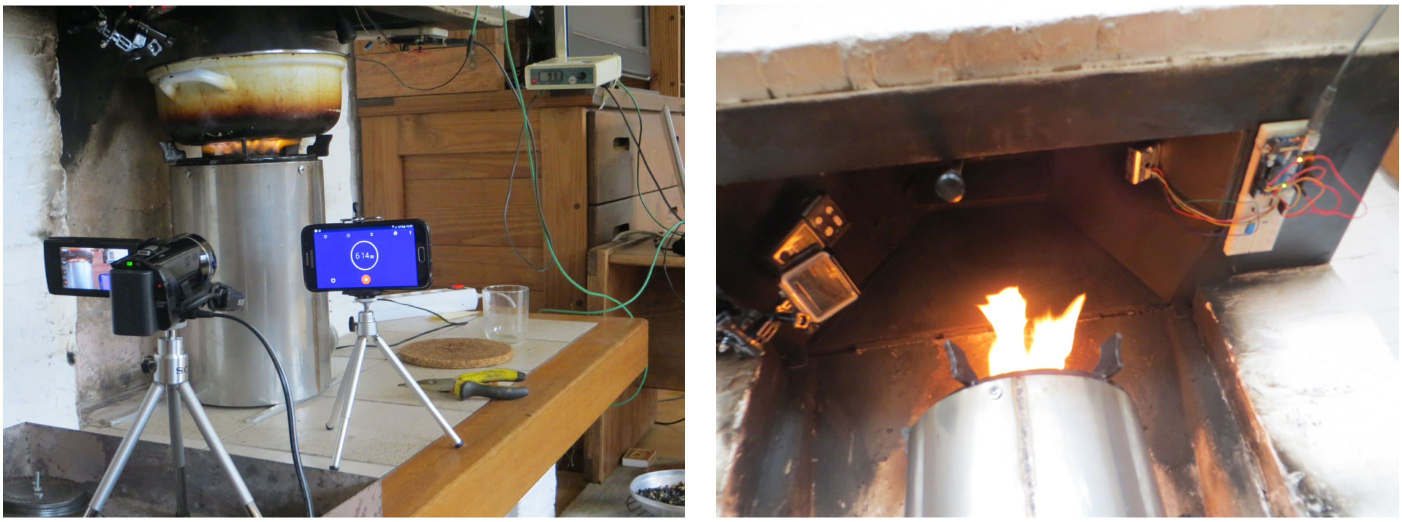


Figure 3 Test setup with measuring devices

Scale

A digital scale was used for measuring the weight of:

- The batch loaded fuel before the test phase
- The remaining fuel and char after each phase
- The water before the test phase
- The water after the test phase
- The starter fuels

The scale has an accuracy of 1 g with a maximum reading of 5500 g.

Temperature sensor

A temperature sensor with multiple probes was used to determine the temperature of; the ambient air, the water in the pot before, after and during the test and the temperature in the duct.

Recording devices

A stopwatch for time measurement, video recorder and camera for video proof and documentation.

Emission

For the emission tests a Ventis mx4 multi-gas monitor was used, to measure the carbon monoxide levels. The device was calibrated before the test to ensure accurate readings. For the PM2.5 measurements, a Sharp GP2Y1010AU0F optical dust sensor was purchased and hooked onto an Arduino board and has an approximate sensitivity of 0.5V/0.1mg/m3. The code used for the Arduino can be found in Appendix 1.

Figure 4 Ventis mx4 multi-gas monitor

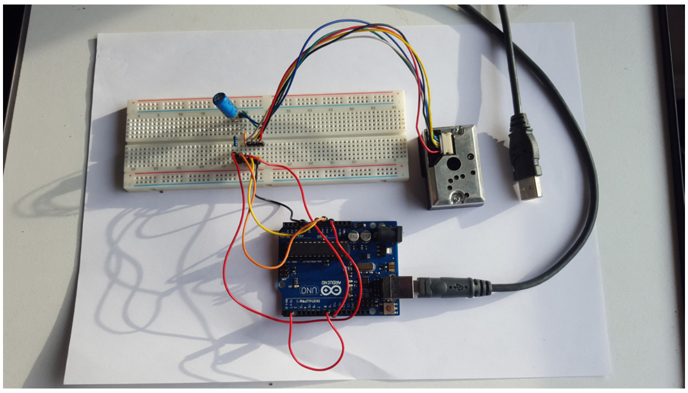


Figure 5 Arduino board with PM2.5 dust sensor

4 METHODS

Measurements from the WBT were recorded in the Excel workbook titled:

WBT_data-calculation_sheet_4.2.3.xls

Which can be obtained from:

http://cleancookstoves.org/technology-and-fuels/testing/protocols.html

This tool provides an easy way to obtain results by calculations which are described in the wbt-4-2-3 protocol in appendix 4. Results presented in this test report are based on the results given by this spreadsheet. The tester is asked to fill out all the gray cells and cells with listboxes, other cells are for calculations.

4.1 Selecting fuel and pot for testing

Ideally the WBT protocol advises on using a 7-liter pot but this can be altered when properly documented. For this test a 3.5-liter pot is used which is filled with 2.5 liters of water for each phase. Reason for this is that there were no larger pots available and would not fit in the testing environment. The material of the pot has an influence on the boiling time, Aluminum has a greater conductivity compared to steel and will therefore boil water faster. The 3.5-liter pot that was available for this test was a

Figure 6 Test setup with measuring devices

4.2 Test procedure for each water boiling test

1. Fill reactor with 450 g of wood pellet
2. Prepare 20 grams of pellet with 10 ml ethanol mix
3. Fill 2.5 liter in pot using the scale (2.5 kg = 2.5 liter)
4. Start PM2.5 measurements on the computer
5. Start CO measurement device + GoPro filming
6. Adjust the fan to low speed
7. Put the pellet/ ethanol mix on the top of the reactor
8. Start fire + Stopwatch
9. Place burner after quality of the gas is good enough
10. Place pot on top of the stove
11. Adjust the fan to high speed
12. (wait for water to boil)
13. Turn fan off and rapidly perform the next steps
14. Place pot on the scale and measure weight
15. Empty reactor and measure char + pellets
16. Separate char and pellets to measure individually
17. Stop data logging recordings and document results

Figure 7 Measuring fuel in the reactor

4.3 Measure

The following data should be measured during for each phase test:

1	Time the burner is placed on the gasifier	
2	Measure and record the ambient conditions: air temperature (°C) & wind conditions	
3	Record background concentrations for CO (ppm), and particulate matter concentrations (μg/m3).	
4	Time the pot is placed on the stove	
5	Temperature of the water boiling (T100)	
6	Time where the water starts boiling	
7	Weight of the pot + water before boiling	
8	Weight of the pot + water after boiling	
9	Weight of the char + pellets	
10	Weight of the char	
11	Weight of the pellets	

Table 1 Example of table that can be filled in during the tests.

4.4 Fuel description

The stove is designed to use pellets as a fuel, for this test pellets from Comfort wood pellets were used:

http://comfortpellets.com/

Information about the fuel such as calorific fuel values were obtained from their website:

http://www.greenmaxx-pellets.nl/wp-content/uploads/downloads/2013/09/Analyse-GREEN-MAXX-03-09-2013.pdf

These values were filled in the "*WBT_data-calculation_sheet_4.2.3.xls*" spreadsheet. This can be seen in the image below:

Version 4.2.4

Fuel description		
Your general description	Comgoed biomassa	
Fuel type	Average Hardwood	
Fuel description	Manufactured	
Average length (cm)	2	
Cross-sectional dimensions (cm x cm)	1	
Default values (looked up)		
Gross calorific value	19.734	HHV, kJ/kg
Net calorific value	18.414	LHV,kJ/kg
Char calorific value	29.500	LHV,kJ/kg
Char carbon content	95%	by mass
If possible, enter a calorific value from measurements of local fuel below.		
/ Check box if you have a measured calorific value		
Measured gross calorific value	19.524	HHV measured, kJ/kg
Measured net calorific value	18.133	LHV, kJ/kg
Assumed net calorific value	18133,44945	LHV, kJ/kg
Values to be used for tests		
Gross calorific value	**19.524**	HHV, kJ/kg
Net calorific value	18.133	LHV, kJ/kg
Fuel carbon content	0,500	by mass
Description of firestarter (e.g. paper, fluid) and small wood or kindling		
(note: Kindling should be weighed and reported with wood)		
For starting the fire, ethanol is used with 20 grams of wood pellet. They are mixed and soaked for 1 minute, after which it is added to the top op the fuel bed. A lighter is then used to ignite the ethanol.		

Figure 8 Screenshot of the entry table in the "WBT_data-calculation_sheet_4.2.3.xls" spreadsheet

5 RESULTS

This chapter presents an overview of each test phase with a short analysis of the data and special notes of the three tests that were executed.

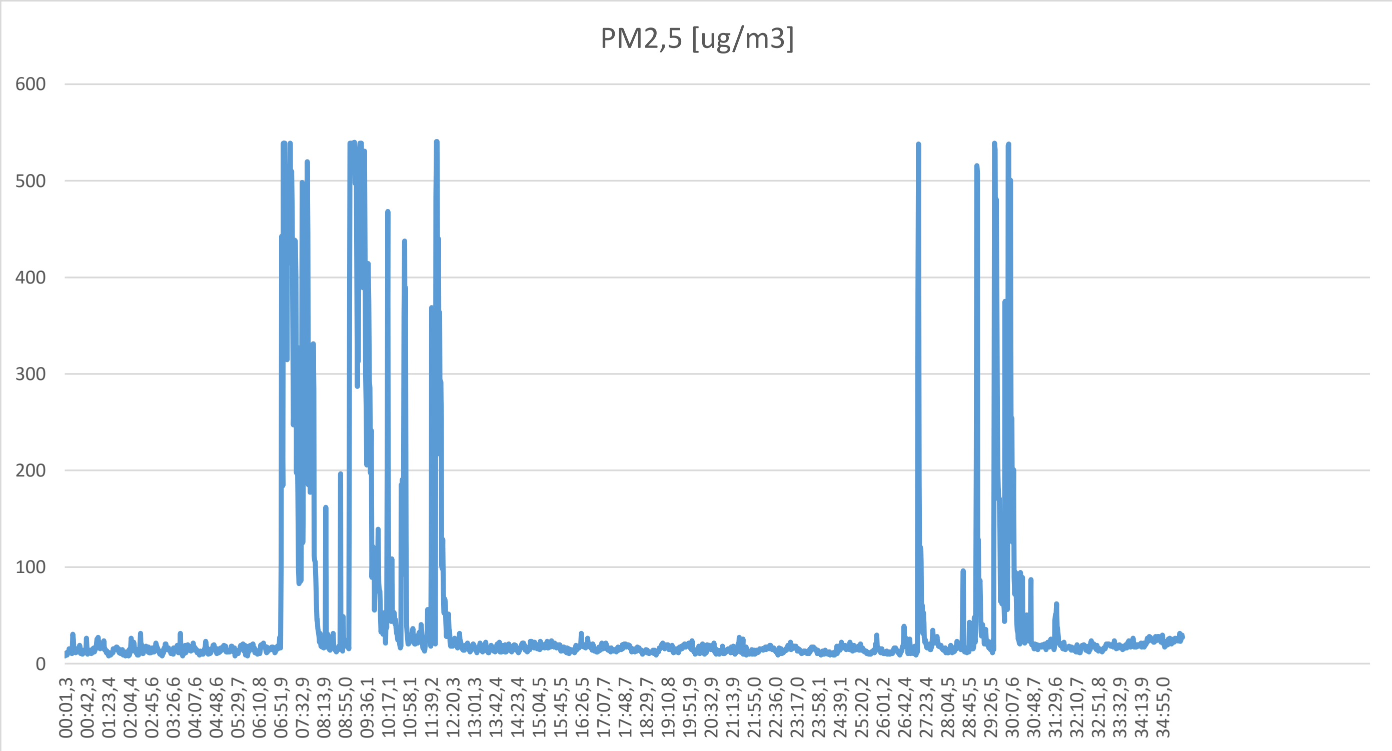
5.1 Cold-start high power test

The results of the cold-start high power test are summarized in the table below.

Nr.	Handling	Measurement
1	Time the burner is placed on the gasifier (successful)	5:30 after start
2	Measure and record the ambient conditions: air temperature (°C) & wind conditions	air temperature (°C): 19,4 Wind conditions: None
3	Record background concentrations for CO (ppm), and particulate matter concentrations (µg/m3).	CO (ppm): 0 PM2.5: 8 (µg/m3)
4	Time the pot is placed on the stove	8:42 minutes
5	Temperature of the water boiling (T100)	100 °C
6	Time where the water starts boiling	19:11 minutes
7	Weight of the pot + water before boiling	4288 g
8	Weight of the pot + water after boiling	4030 g
9	Weight of the char + pellets	199 g
10	Weight of the char	41 (some hot char is burned during the weight measurement)
11	Weight of the pellets	156

Table 2 Results from the cold-start high power test

There was a small problem with igniting the gas when the burner was placed. This immediately shows an increase of PM2.5 in the test chamber. It is assumed that the generated gas did not reach high enough levels of combustibles or too much moisture from the pellets was inside the gas. Other tests show that this can be avoided when waiting 2 minutes longer before placing the burner.



Graph 1 PM2.5 reading from the cold start

The picture below shows the char separated from the pellets so they can be weight independently. Reason why this is important is because the char has a higher calorific value and will therefore have a different influence on the efficiency calculations.

Figure 9 Pellets and char separated for individual weight measurement

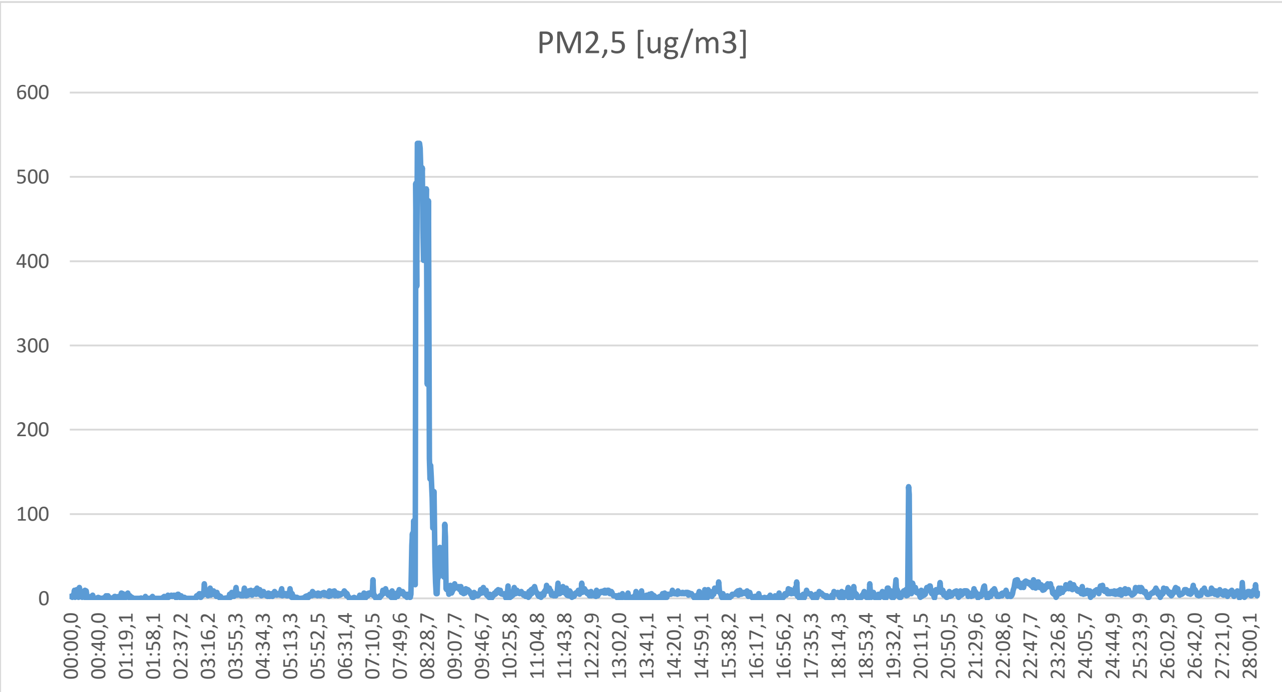
5.2 Hot-start high power test

The results of the cold-start high power test are summarized in the table below.

Nr.	Handling	Measurement
1	Time the burner is placed on the gasifier (successful)	7:23 minutes after start
2	Measure and record the ambient conditions: air temperature (°C) & wind conditions	air temperature (°C): 19,4 Wind conditions: None
3	Record background concentrations for CO (ppm), and particulate matter concentrations (µg/m3).	CO (ppm): 3 PM2.5: 11 (µg/m3)
4	Time the pot is placed on the stove	7:48 minutes
5	Temperature of the water boiling (T100)	100 °C
6	Time where the water starts boiling	18:20 minutes
7	Weight of the pot + water before boiling	4286 g
8	Weight of the pot + water after boiling	4036 g
9	Weight of the char + pellets	230 g
10	Weight of the char	51 (some hot char is burned during the weight measurement)
11	Weight of the pellets	178

Table 3 Results from the hot-start high power test

Looking at the graph below a longer wait for placing the burner went much smoother compared to the cold start test. Only for a short period is the particulate matter emitted in the air. The spike in the end is due to the termination of the gasification process. The fan is turned off and the burner is removed. The lack of oxygen distinguishes the flame at the burner, but once the burner is completely removed the ambient air supplies enough oxygen for the produce gas to catch fire again.



Graph 2 PM2.5 reading from the hot start

The picture below shows the char separated from the pellets so they can be weight independently. Reason why this is important is because the char has a higher calorific value and will therefore have a different influence on the efficiency calculations.

Figure 10 Pellets and char separated for individual weight measurement

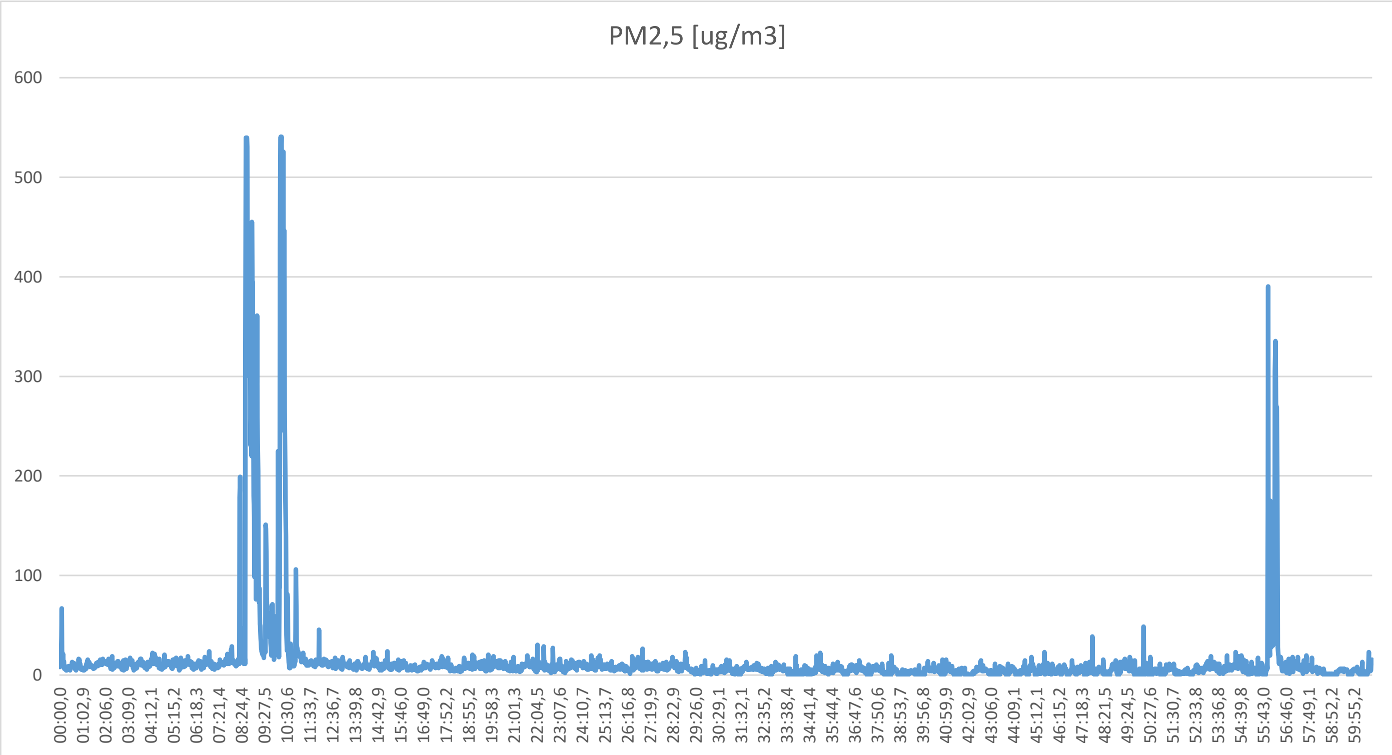
5.3 Simmer test

The results of the simmer test are summarized in the table below.

Nr.	Handling	Measurement
1	Time the burner is placed on the gasifier (successful)	7:15 minutes after start
2	Measure and record the ambient conditions: air temperature (°C) & wind conditions	air temperature (°C): 19,4 Wind conditions: None
3	Record background concentrations for CO (ppm), and particulate matter concentrations (µg/m3).	CO (ppm): 3 PM2.5: 11 (µg/m3)
4	Time the pot is placed on the stove	7:30 minutes
5	Temperature of the water before test	95 °C
6	Water temperature during test	100 °C
7	Weight of the pot + water before boiling	4300 g
8	Weight of the pot + water after boiling	3022 g
9	Weight of the char + pellets	93 g
10	Weight of the char	93 g
11	Weight of the pellets	0 g

Table 4 Results from the simmer test

The graph below shows the particulate matter emitted during the simmer test. It can be noted that only during the burner placement and removal that more particulate matter is emitted. During the simmer test there is no significant difference between emitted particles in the different tests.



Graph 3 PM2.5 reading from the simmer test

The flame during the simmer test is shown in the image below. The test states that the temperature of the water in the pot should maintain at a maximum difference of 6 degrees Celsius of the established boiling point. During the test the water had a constant temperature of 100 degrees but could not go lower and maintain a stable flame. Efficiency might therefore be compromised as too much energy is transferred to the pot.

Figure 11 Flame during the simmer test

6 RESULTS FROM WBT CALCULATION SHEET

The table below summarized the measured performance of three tests. The data is obtained by filling in the collected measurements of the test in the WBT_data-calculation_sheet_4.2.3.xls" spreadsheet.

1. HIGH POWER TEST (COLD START)	**Units**	**Test 1**
Time to boil Pot # 1	min	11
Temp-corrected time to boil Pot # 1	min	9
Burning rate	g/min	19
Thermal efficiency	%	57%
Specific fuel consumption	g/liter	54
Temp-corrected specific consumption	g/liter	45
Temp-corrected specific energy cons	kJ/liter	822
Firepower	watts	5.602

2. HIGH POWER TEST (HOT START)	**Units**	**Test 1**
Time to boil Pot # 1	min	11
Temp-corrected time to boil Pot # 1	min	9
Burning rate	g/min	16
Thermal efficiency	%	67%
Specific fuel consumption	g/liter	45
Temp-corrected specific consumption	g/liter	38
Temp-corrected specific energy cons	kJ/liter	684
Firepower	watts	4.889

3. HIGH POWER TEST (HOT START)	**Units**	**Test 1**
Burning rate	g/min	8
Thermal efficiency	%	48%
Specific fuel consumption	g/liter	123
Temp-corrected specific energy cons.	KJ/liter	2.223
Firepower	Watts	2.269
Turn down ratio	--	2.47

Table 5 test results of the three phases

The highest efficiency obtained was 67% during the hot start with a time to boil of 11 minutes. The lowest thermal efficiency was obtained during the simmer test 48%.

7 CONCLUSION

The stove has excellent performance on thermal efficiency and can be ranked as TIER 4 in the performance scale. These results are obtained having ideal conditions and might not be directly obtained by inexperienced users. The stove might operate inefficiently if too much power is provided for the needed task. All test results are highly dependent on the power level that is chosen. During the simmer test the flame was too powerful as it kept the water boiling during the entire test. A better turn down ratio might increase the efficiency in this phase.

Looking at the PM2.5 during the operation there is almost no harmful smoke emitted. However, when the burner is not placed correctly (as the cold start test shows) in unventilated rooms it can be dangerous for users. High concentrations of produce gas will fill the room and they should therefore be instructed and trained.

8 RECOMMENDATIONS

Some recommendations can be done based on the testing results.

- Further improved can be done towards usability when placing the burner.
- It is always advised to use improved cookstoves in a well ventilated room, preferably under a chimney.
- The data from the carbon monoxide measurement device are not yet obtained and should be analyzed in a later stage.
- Same test can be done to identify the suitability of the stove with other types of biomass fuels.
- The set-up of the measuring equipment was not standardized but give a good indication of the performance. A test can be done at a different institute to compare the results.

Statement by TU Delft

This is to testify that this test report of 09-03-2016, provides testing results and interpretations of the CCS gasifier stove. TU Delft has no financial interest with CCS or the stove that has been developed by its MSc. graduate student Pascal Franken.

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Ass. Professor

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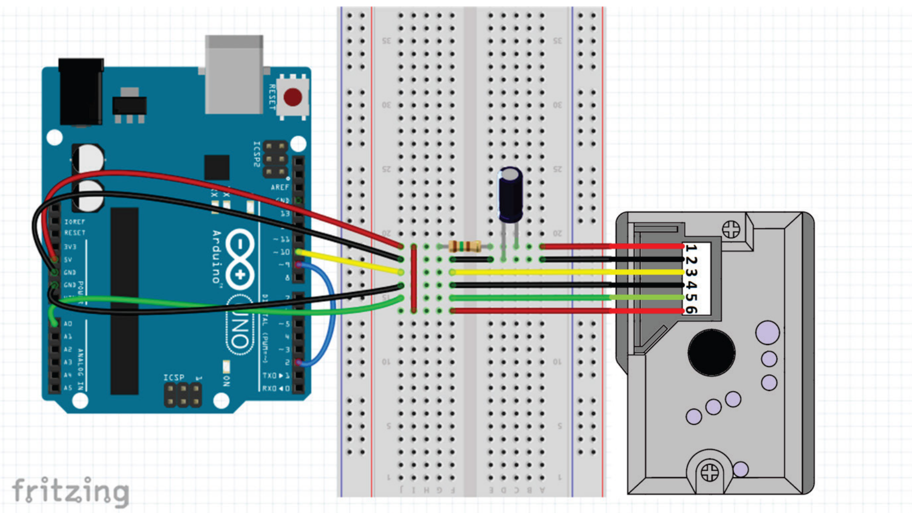
APPENDIX 1 ARDUINO CODE

```
// Paul's GP2Y1010AU0F Dust Sensor Sketch

/*
Arduino Uno (ATMEGA328) Port Allocations:
A0:     A/D:                      Dust Sensor Analog Signal
D2:     INT0 I/P:                 Dust Sensor Interrupt - Link to D9
D9:     Timer 1 OC1A PWM O/P:     Dust Sensor Samples - Link to D2
D10:    Timer 1 OC1B PWM O/P:     Dust Sensor LED Pulses
*/

#define VOLTAGE 5.0 // Arduino supply voltage

// Download the Timer 1 Library (r11) from:
// http://playground.arduino.cc/Code/Timer1
// https://code.google.com/p/arduino-timerone/downloads/list

#include <TimerOne.h>

/*
   Smoothing
   Reads repeatedly from an analog input, calculating a running average.
   Keeps readings in an array and continually averages them.
   Created 22 April 2007
   By David A. Mellis  <dam@mellis.org>
   modified 9 Apr 2012
   by Tom Igoe
   http://www.arduino.cc/en/Tutorial/Smoothing
   This example code is in the public domain.
*/

/* With thanks to Adafruit for the millis code - plagiarised from the Adafruit GPS Library */

const int numReadings = 100;    // samples are taken at 100Hz so calculate average over 1sec

int readings[numReadings];      // the readings from the analog input
int readIndex = 0;              // the index of the current reading
long int total = 0;             // the running total
int latest_reading = 0;         // the latest reading
int average_reading = 0;        // the average reading

int dustPin = A0;
```

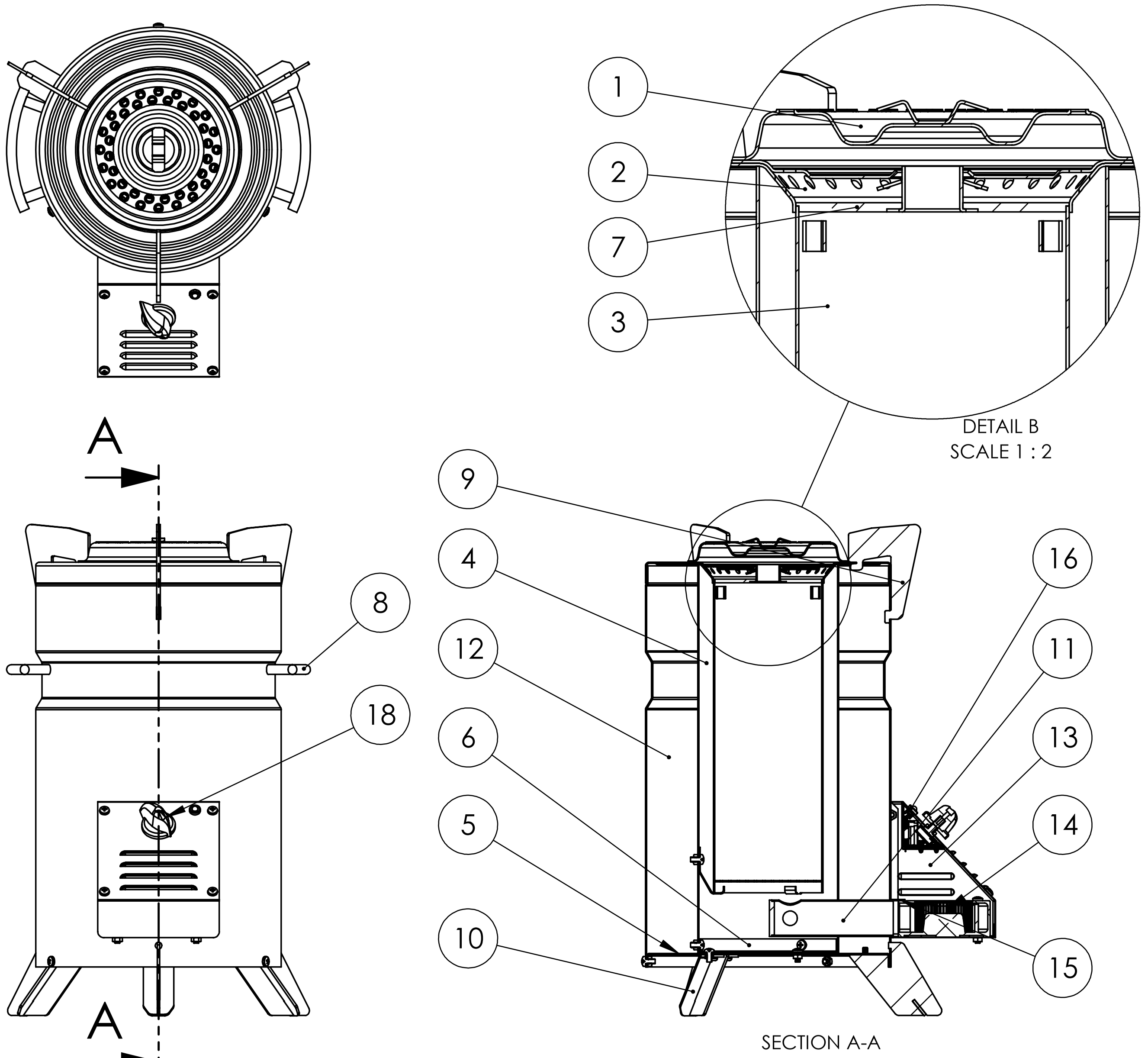
```
// Initialisation routine

void setup()
{
  Serial.begin(9600);

  // Configure PWM Dust Sensor Sample pin (OC1A)
  pinMode(9, OUTPUT);
  // Configure PWM Dust Sensor LED pin (OC1B)
  pinMode(10, OUTPUT);
  // Configure INT0 to receive Dust Sensor Samples
  pinMode(2, INPUT_PULLUP);

  // Put Timer 1 into 16-bit mode to generate the 0.32ms low LED pulses every 10ms
  // A0 needs to be sampled 0.28ms after the falling edge of the LED pulse - via INT0 driven by OC1A (D9)
  Timer1.initialize(10000); // Set a timer of length 10000 microseconds (or 10ms - or 100Hz)
  Timer1.pwm(10, 991); // Set active high PWM of (10 - 0.32) * 1024 = 991
  Timer1.pwm(9, 999); // Set active high PWM of (10 - 0.28) * 1024 = 995 BUT requires a fiddle factor making it 999

  // Attach the INT0 interrupt service routine
  attachInterrupt(0, takeReading, RISING); // Sample A0 on the rising edge of OC1A

  // Initialise sample buffer
  for (int thisReading = 0; thisReading < numReadings; thisReading++) {
     readings[thisReading] = 0;
   }
}

// Dust sample interrupt service routine
void takeReading() {
   // subtract the last reading:
   total = total - readings[readIndex];
   // read from the sensor:
   latest_reading = analogRead(dustPin);
   readings[readIndex] = latest_reading;
   // add the reading to the total:
   total = total + latest_reading;
   // advance to the next position in the array:
   readIndex = readIndex + 1.0;

   // if we're at the end of the array...wrap around to the beginning:
   if (readIndex >= numReadings) readIndex = 0.00;

   // calculate the average:
   average_reading = total / numReadings; // Seems to work OK with integer maths - but total does need to be long int
}
```

```
void loop()                          // run over and over again
{
  // if millis() or timer wraps around, we'll just reset it
  if (timer > millis())  timer = millis();

  // approximately every second or so, print out the dust reading
  if (millis() - timer > 1000) {
    timer = millis(); // reset the timer

    float latest_dust = latest_reading * (VOLTAGE / 1023.00);
    float average_dust = average_reading * (VOLTAGE/ 1023.00);
    float dust_density = 0.00;

    dust_density = (0.17 * average_dust - 0.10)*1000;

    Serial.print(" - Dust Density [ug/m3]: ");
    Serial.print (dust_density);
    Serial.print (',');
    Serial.print("\t\tLatest Dust Reading (V): ");
    Serial.print(latest_dust);
     Serial.print (',');
    Serial.print("\t\tAverage Dust Reading (V): ");
    Serial.println(average_dust);
  }
}
```

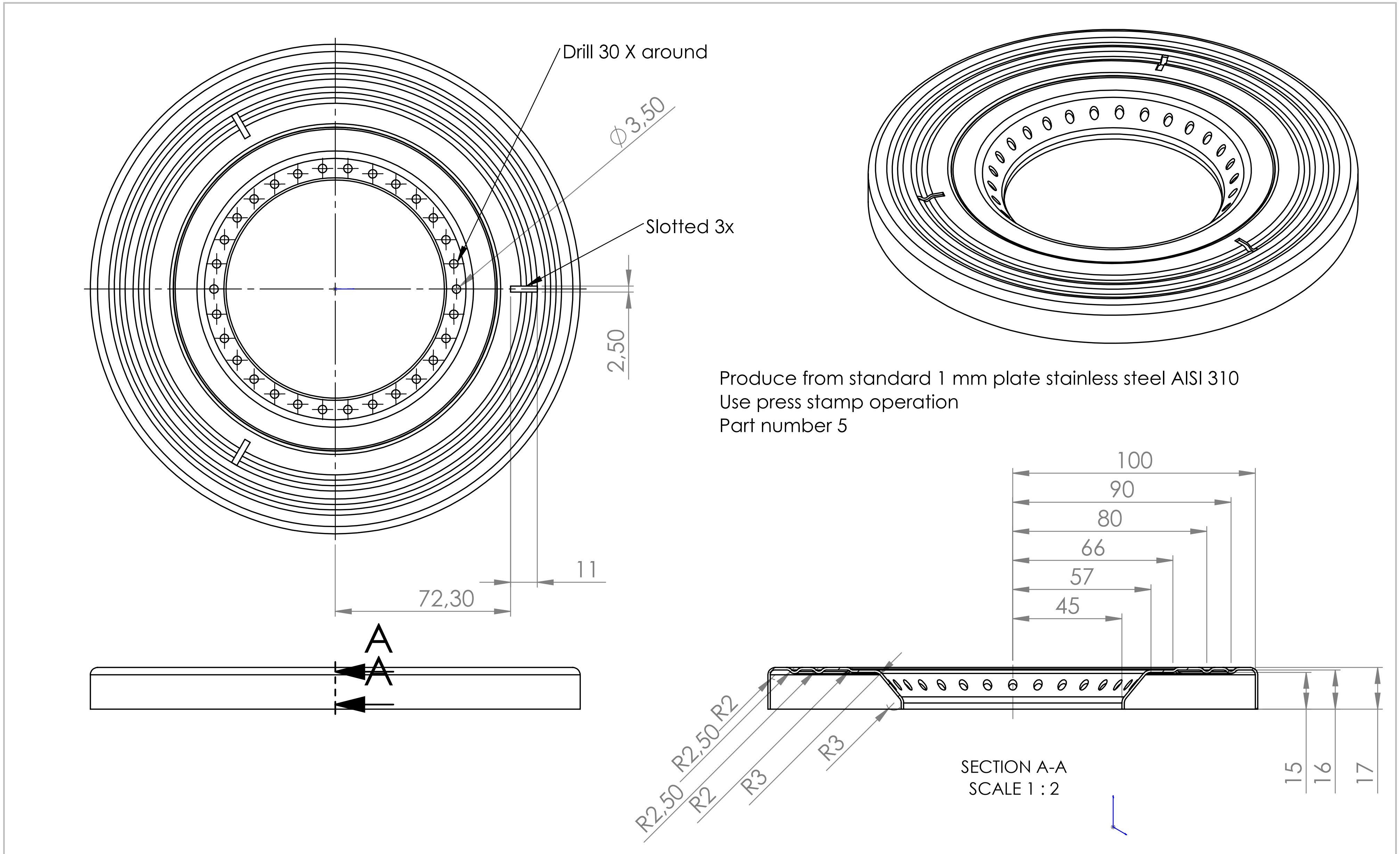


APPENDIX K: TECHNICAL DRAWINGS FINAL DESIGN

no	part name	QTY.
1	Gasifier_Burner_ASSEM	1
2	Gasifier_Top plate_part	1
3	Gasifier_Reactor_ASSEM	1
4	Gasifier_Inner tube_ASSEM	1
5	Gasifier_Bottom plate_part	1
6	Gasifier_Bottom connection ring_part	1
7	Gasifier_Reactor cap_ASSEM	1
8	Gasifier_handle_ASSEM	2
9	Gasifier_pot support_ASSEM	1
10	Gasifier_feet_ASSEM	3
11	Gasifier_Air-tube_ASSEM	1
12	Gasifier_body_ASSEM	1
13	Gasifier_Electronic box_ASSEM	1
14	DC Blower 75mm x 75mm x 30mm_Part_00	1
15	Gasifier_DC Blower_connection_part	1
16	Led holder	1
17	Gasifier_electronics_ASSEM	1
18	Rotary switch knob_Part	1
19	PHT 4x8x7.3-type I-D-S	6
20	B18.6.7M - M4 x 0.7 x 8 Type I Cross Recessed PHMS --8S	20
21	B18.6.7M - M4 x 0.7 x 35 Type I Cross Recessed PHMS --35S	2
22	B18.2.4.1M - Hex nut, Style 1, M4 x 0.7 --D-S	22
23	PCB spacer	4



TU Delft Industrial Design Engineering	benaming CCS_Gasifier_ASSEM_00_DRW	schaal 1:5 getekend Pascal	datum 1-4-2016 groep <<groep>>	maateenheid mm formaat A4 tekeningnummer 01

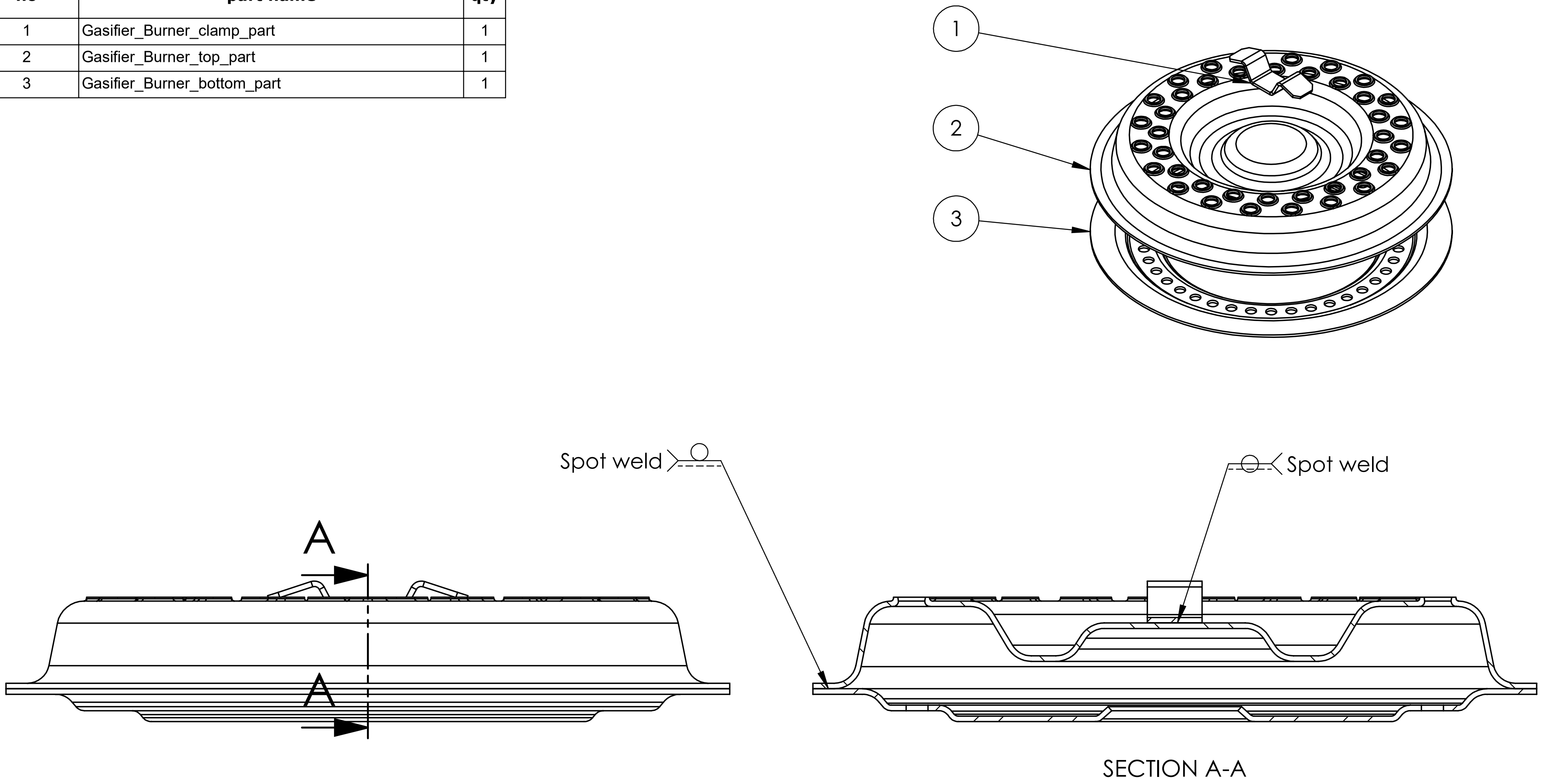


TU Delft
Industrial Design Engineering

benaming Gasifier_Top plate_part_5_DRW

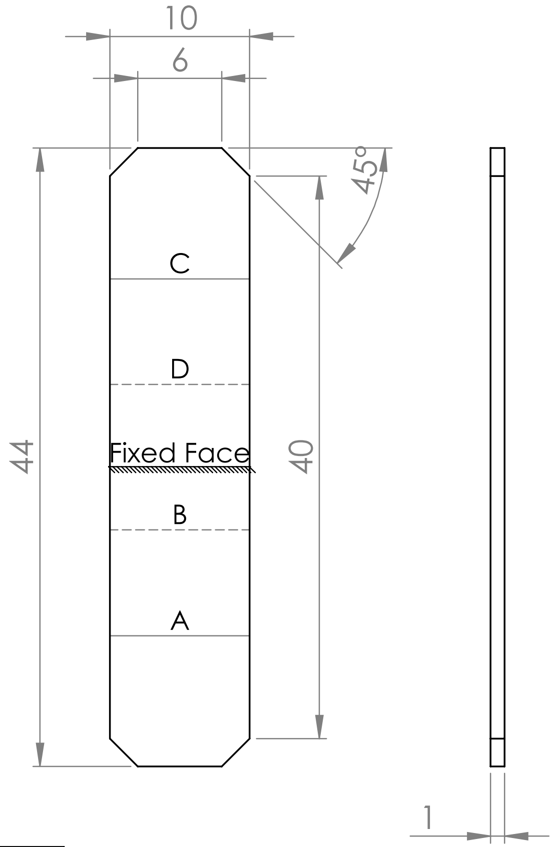
datum 1-4-2016
maateenheid <<maateenheid>>
schaal 1:5
groep <<groep>>
formaat A4
tekeningnummer <<tekeningnummer>>
getekend <<naam>>

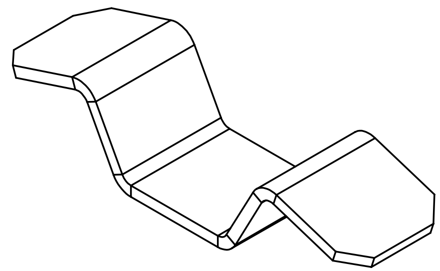
no	part name	qty
1	Gasifier_Burner_clamp_part	1
2	Gasifier_Burner_top_part	1
3	Gasifier_Burner_bottom_part	1



TU Delft Industrial Design Engineering	benaming Gasifier_Burner_ASSEM_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

Produce from 1 mm plate Stainless steel AISI202
Manual bending and cutting
Part number 1
Produce 4X

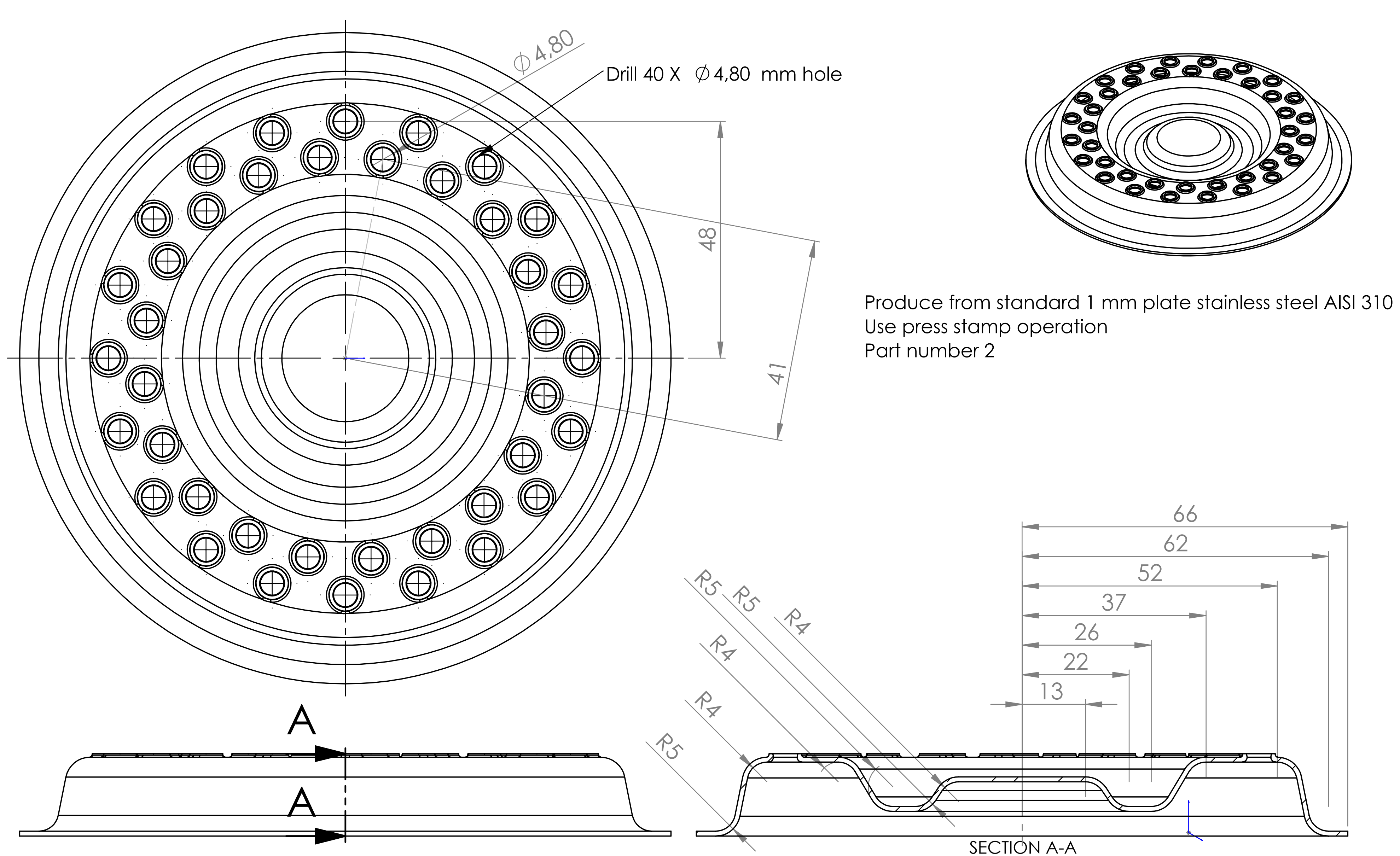




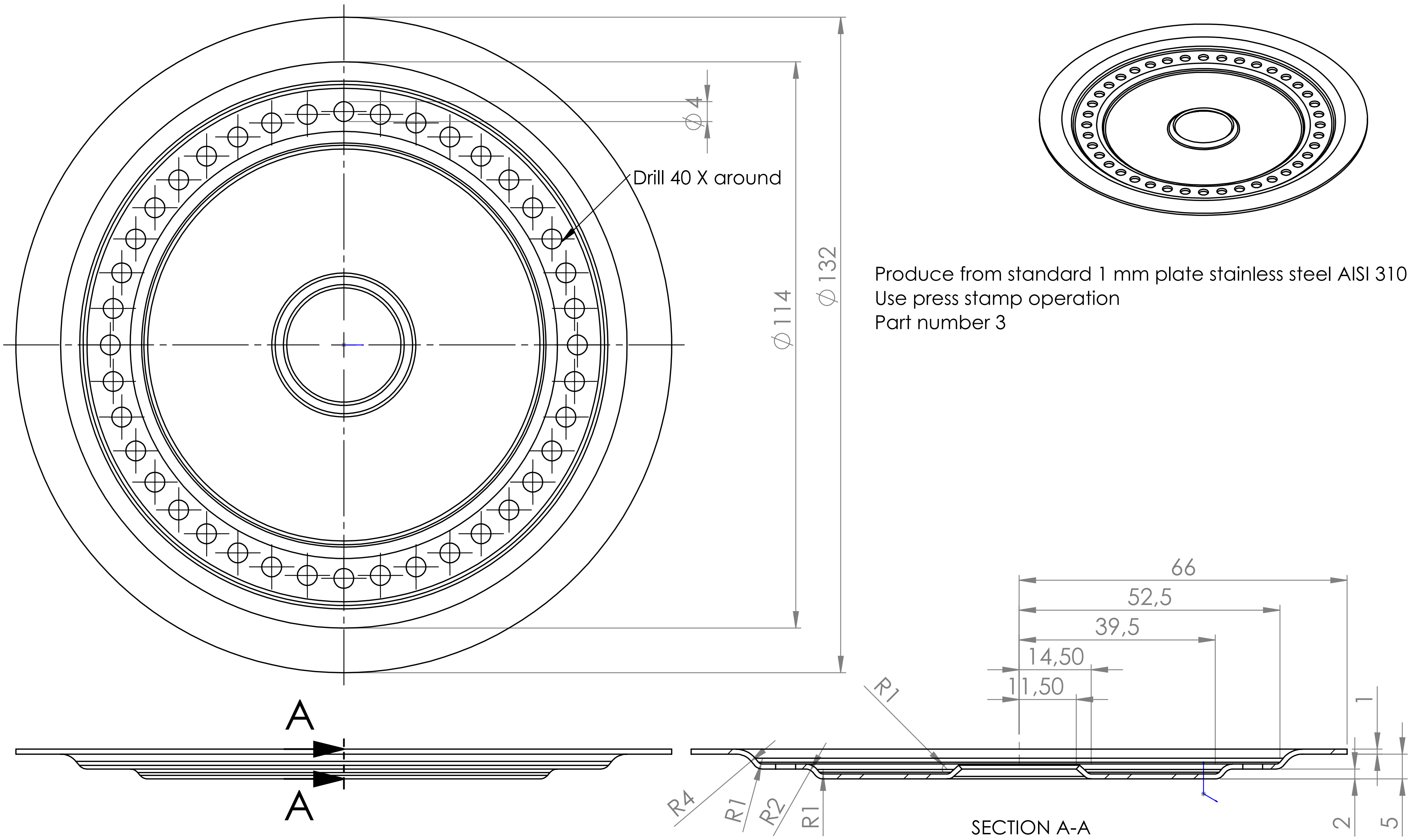
Tag	Direction	Angle	Inner Radius
A	UP	80°	1
B	DOWN	62°	1
C	UP	80°	1
D	DOWN	62°	1

TU Delft
Industrial Design Engineering

benaming Gasifier_Universal clamp reactor cap_part_1_Part
datum 1-4-2016
maateenheid <<maateenheid>>
schaal 2:1
groep <<groep>>
formaat A4
tekeningnummer <<tekeningnummer>>
getekend <<naam>>



TU Delft Industrial Design Engineering	benaming Gasifier_Burner_top_part_2_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

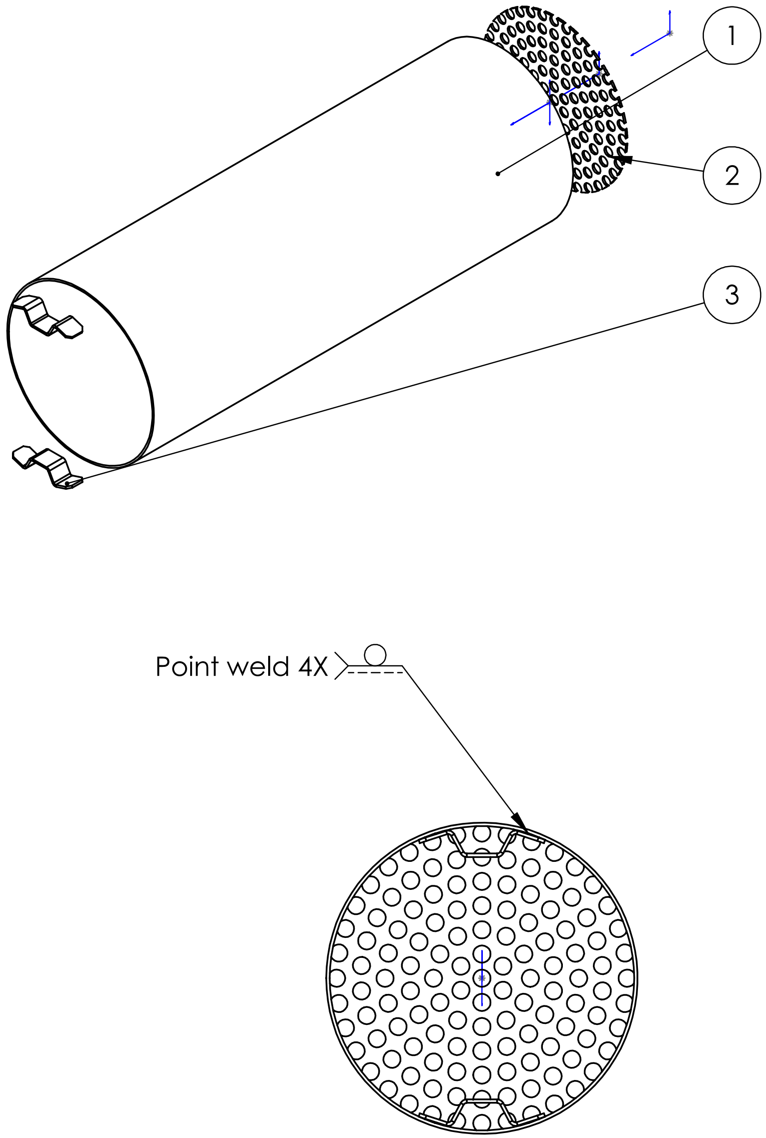


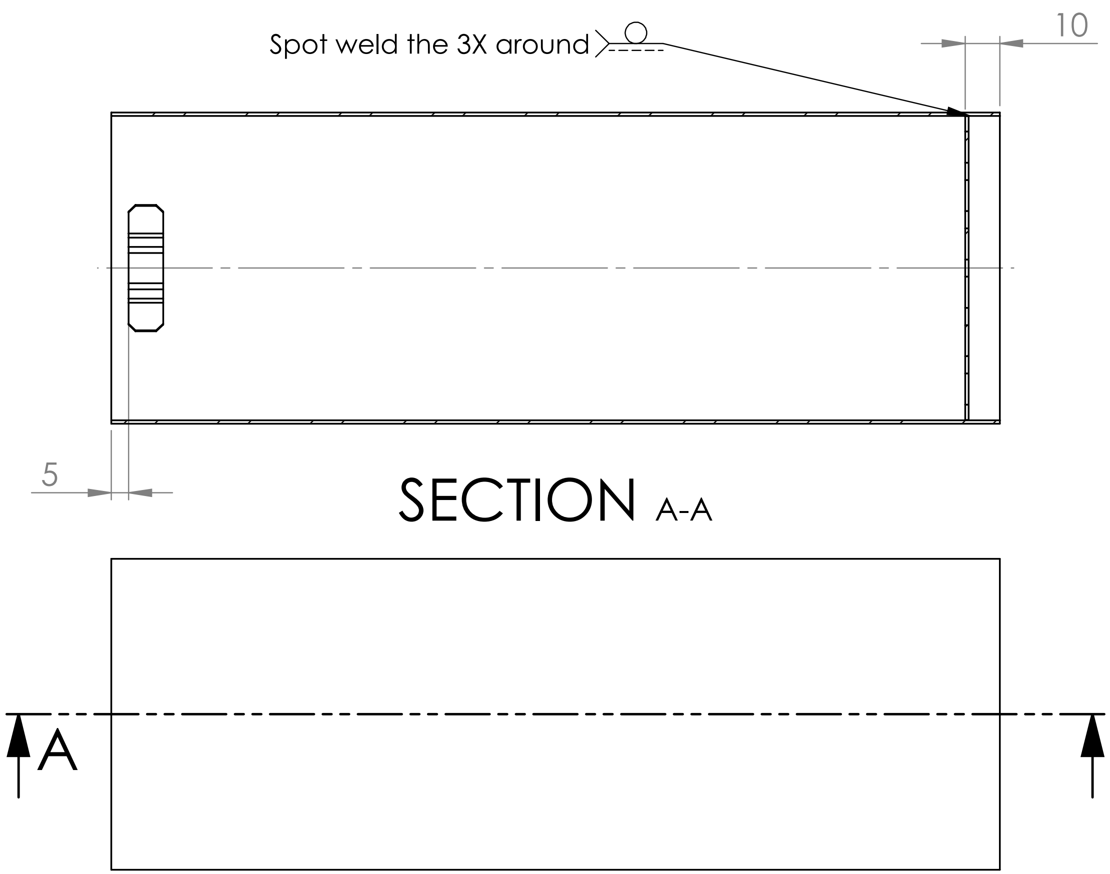
Produce from standard 1 mm plate stainless steel AISI 310
Use press stamp operation
Part number 3

TU Delft Industrial Design Engineering	benaming Gasifier_Burner_bottom_part_3_DRW	schaal 1:1 getekend <<naam>>	datum 1-4-2016 groep <<groep>>	maateenheid <<maateenheid>> formaat A4 tekeningnummer <<tekeningnummer>>

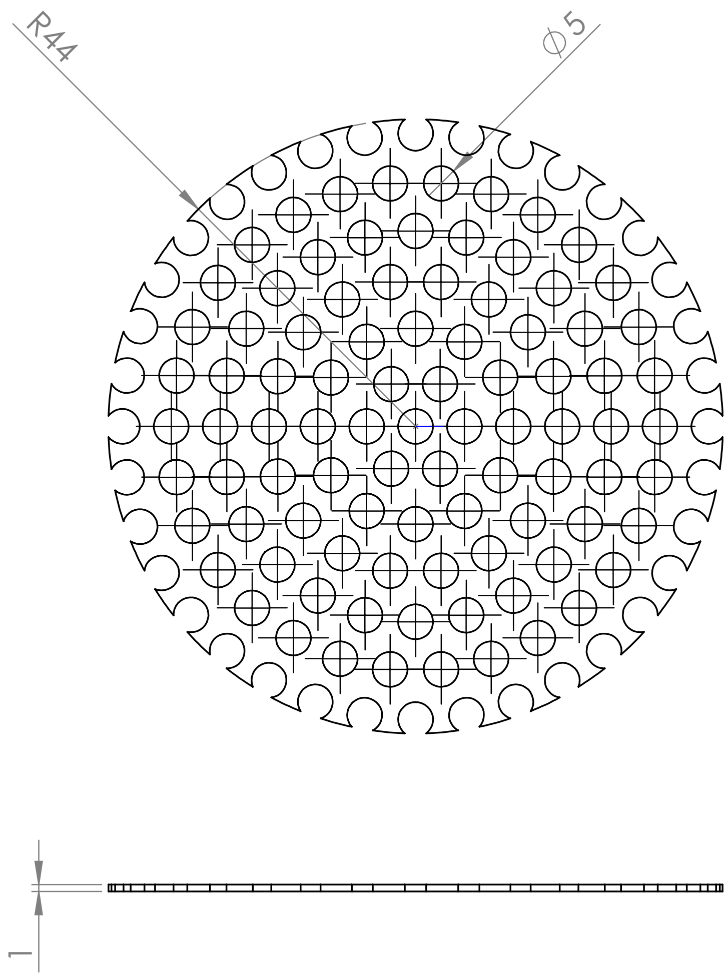
no	part name	qty
1	Gasifier_reactor tube_part	1
2	Gasifier_grade_part	1
3	Gasifier_Univeral clamp reactor_part	2

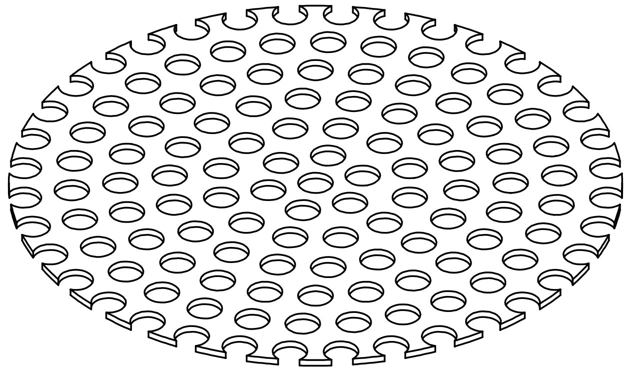
Use universal clamp 2X
Point weld operations 4X
Weld opposite of each other





TU Delft Industrial Design Engineering	benaming Gasifier_Reactor_ASSEM_DRW		datum 1-4-2016		maateenheid <<maateenheid>>
		schaal 1:2	groep <<groep>>	formaat A4	tekeningnummer <<tekeningnummer>>
		getekend <<naam>>			

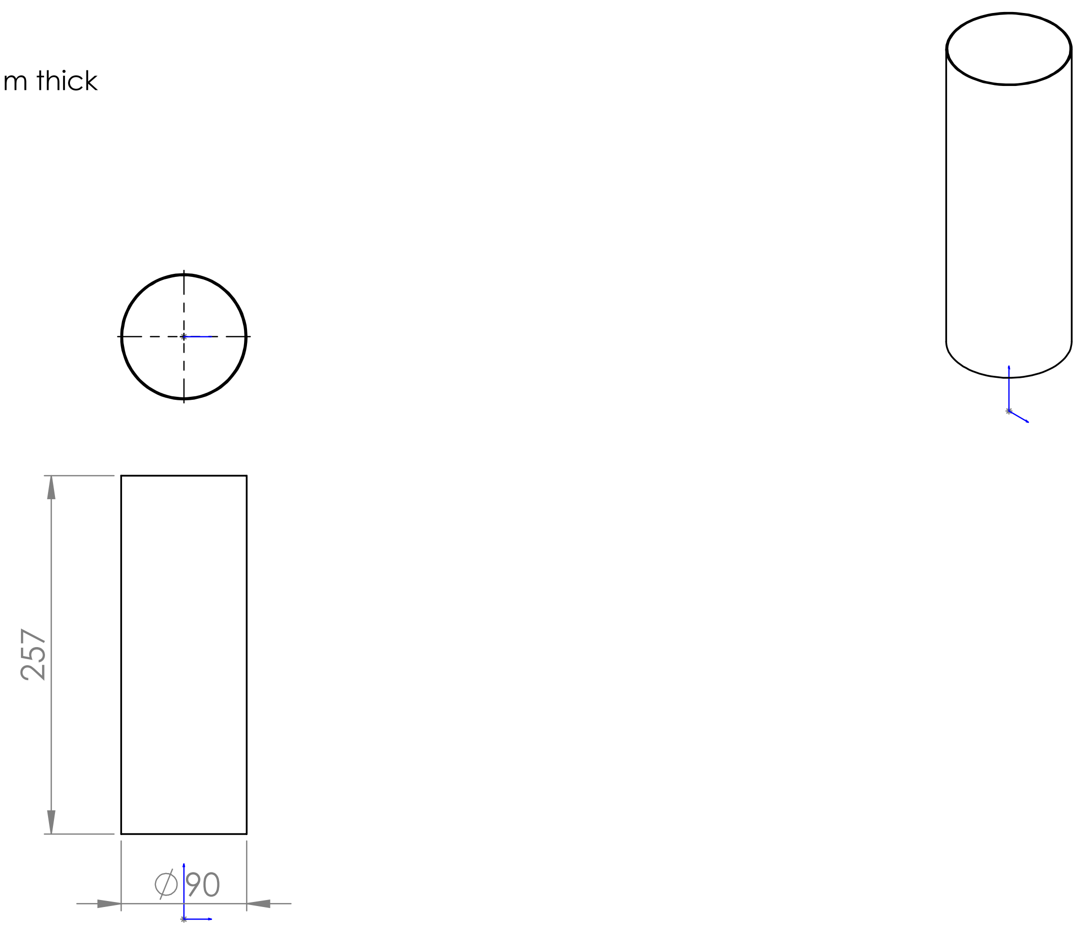




Produce from standard 1 mm stainless steel AISI 310
Use blanking operation
Part number 26
Produce from pre perforated sheet with 5 mm holes

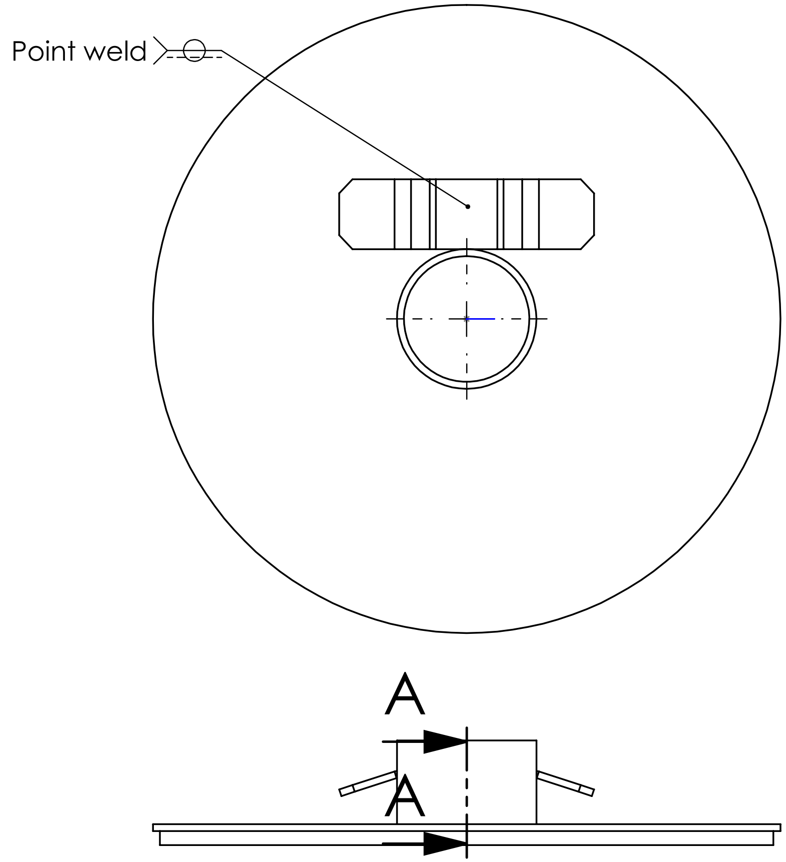
TU Delft Industrial Design Engineering	benaming Gasifier_grade_part_26_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4	tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

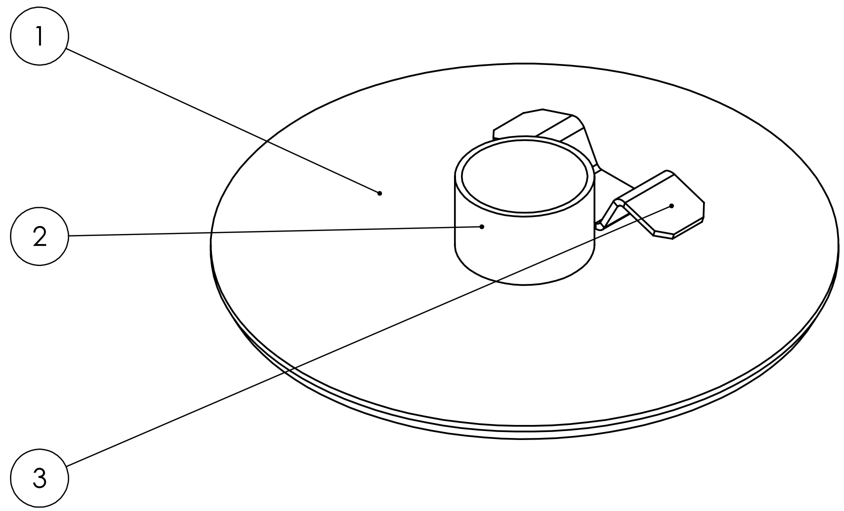
Produce from carbon tube JISG3141 1 m thick
Part number 7

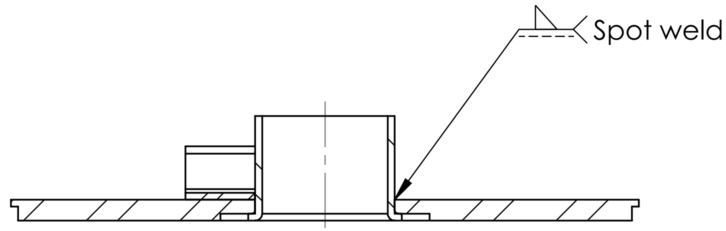


TU Delft Industrial Design Engineering	benaming Gasifier_reactor tube_part_7_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:5	groep <<groep>>	formaat A4 | tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

no	part name	qty
1	Gasifier_Reactor cap_part	1
2	Gasifier_Reactor cap_tube_part	1
3	Gasifier_Universal clamp reactor cap_part	1

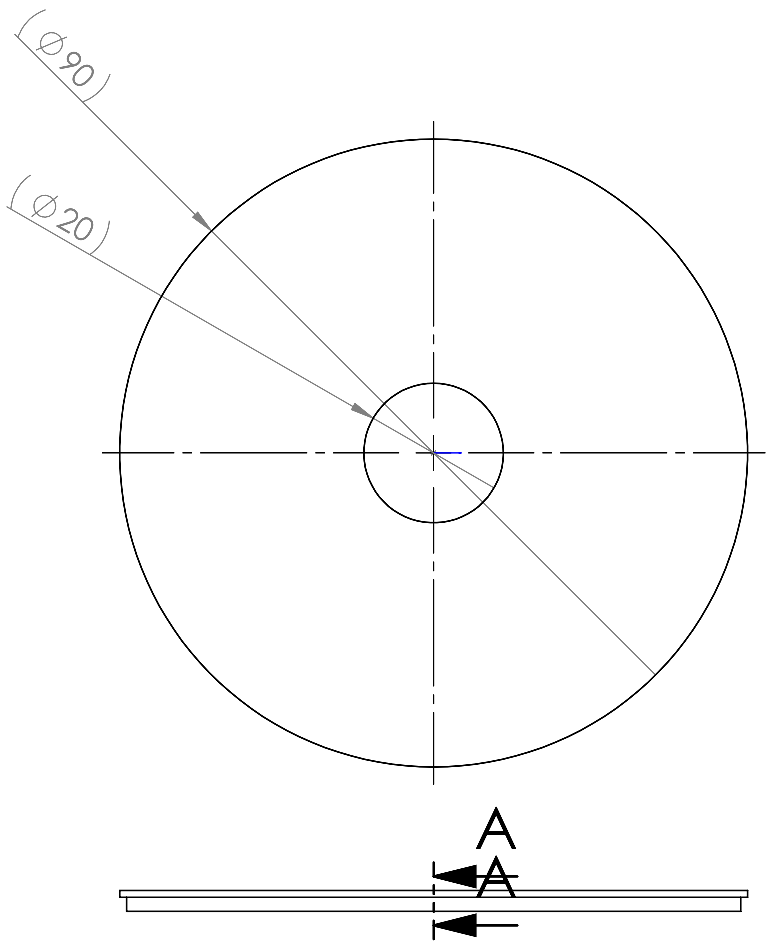


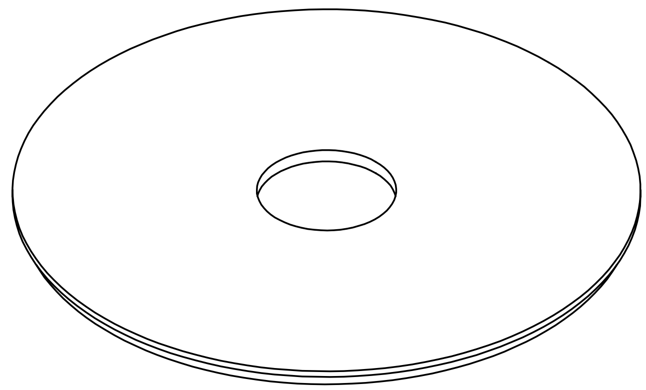




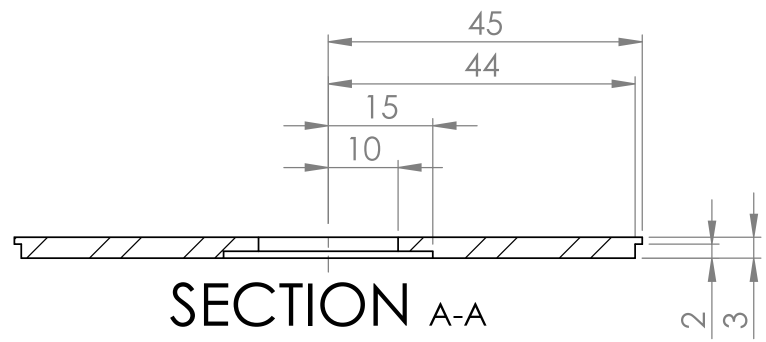
SECTION A-A

TU Delft Industrial Design Engineering	benaming Gasifier_Reactor cap_ASSEM_DRW	schaal 1:1 getekend <<naam>>	datum 1-4-2016 groep <<groep>>	formaat A4	maateenheid <<maateenheid>> tekeningnummer <<tekeningnummer>>



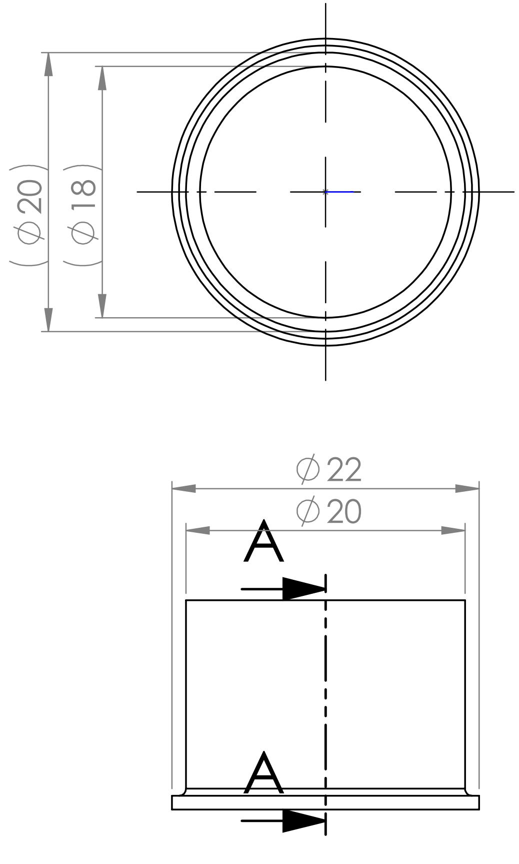


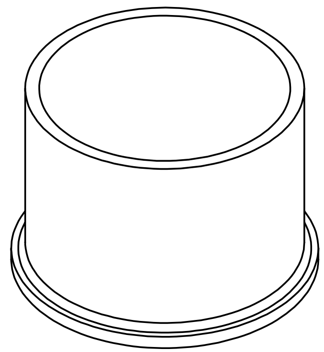
Produce from standard 90 mm rod Carbon steel JI SG3141
Use turning machine
Part number 4

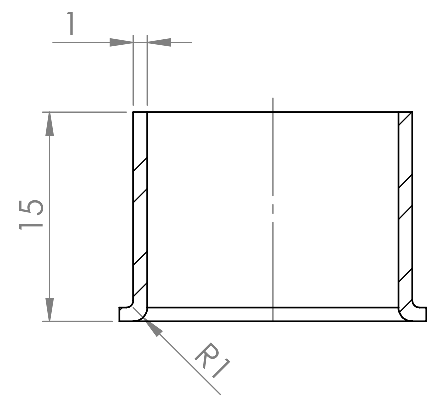


TU Delft Industrial Design Engineering	benaming Gasifier_Reactor cap_part_4_DRW	schaal 1:1	datum 1-4-2016	maateenheid <<maateenheid>>
		getekend <<naam>>	groep <<groep>>	formaat A4
				tekeningnummer <<tekeningnummer>>

Produce from standard 20 mm tube Carbon steel JI SG3141
Cut to length
Bend flange outward
Part number 28





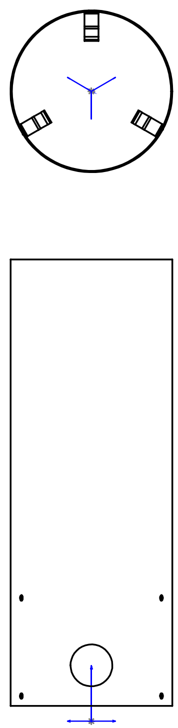


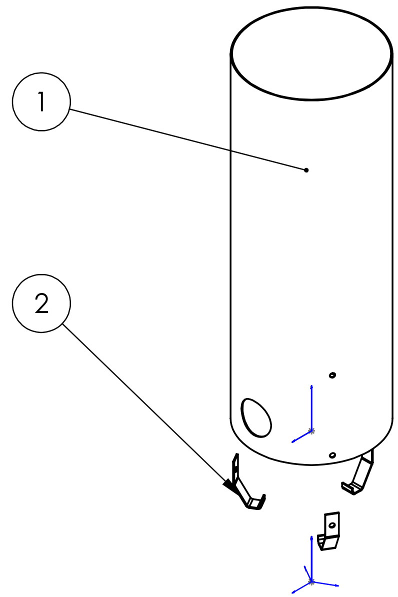
SECTION A-A

TU Delft Industrial Design Engineering	benaming Gasifier_Reactor cap_tube_part_28_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 2:1	groep <<groep>>	formaat A4
		getekend <<naam>>		tekeningnummer <<tekeningnummer>>

no	part name	qty
1	Gasifier_inner tube_part	1
2	Gasifier_reactor holder_part	3

Use M4 nut 3x
Use M4 screw pan head 8 mm 3X





TU Delft
Industrial Design Engineering

benaming Gasifier_Inner tube_ASSEM_DRW

schaal 1:5

getekend <<naam>>

datum 1-4-2016

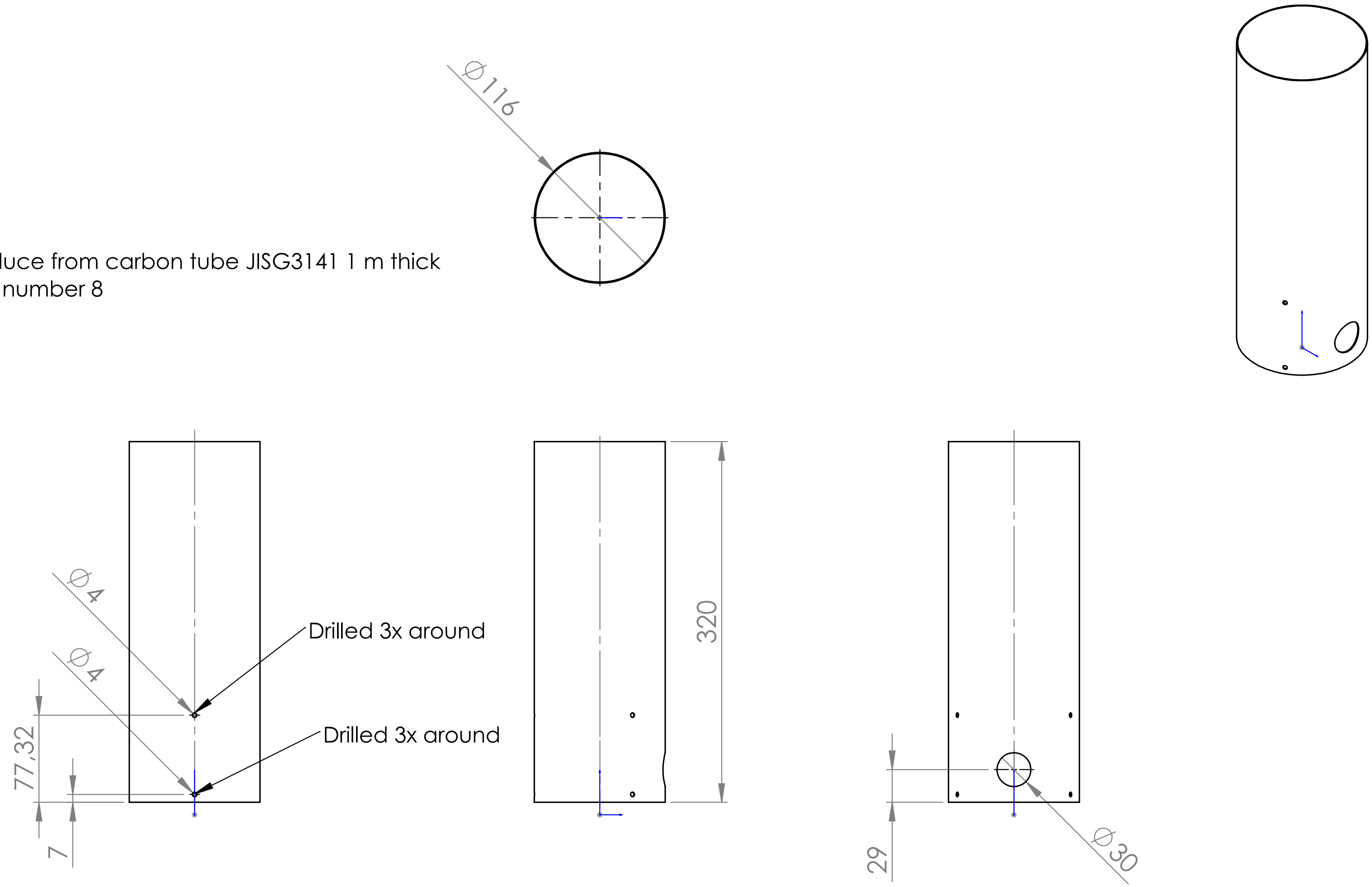
groep <<groep>>

formaat A4

maateenheid <<maateenheid>>

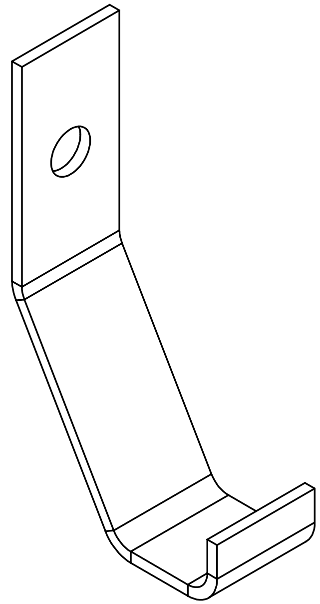
tekeningnummer <<tekeningnummer>>

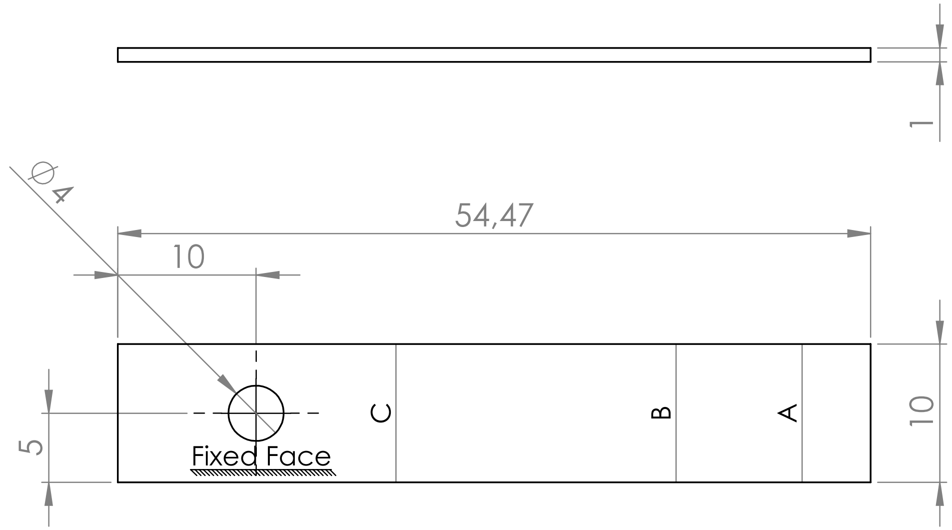
Produce from carbon tube JISG3141 1 m thick
Part number 8



TU Delft Industrial Design Engineering	benaming Gasifier_inner tube_part_8_DRW	schaal 1:5	datum 1-4-2016	maateenheid <<maateenheid>>
		getekend <<naam>>	groep <<groep>>	formaat A4
				tekeningnummer <<tekeningnummer>>

Produce from standard 1 mm plate Carbon steel JI SG3141
Manual bending operation
Part number 11

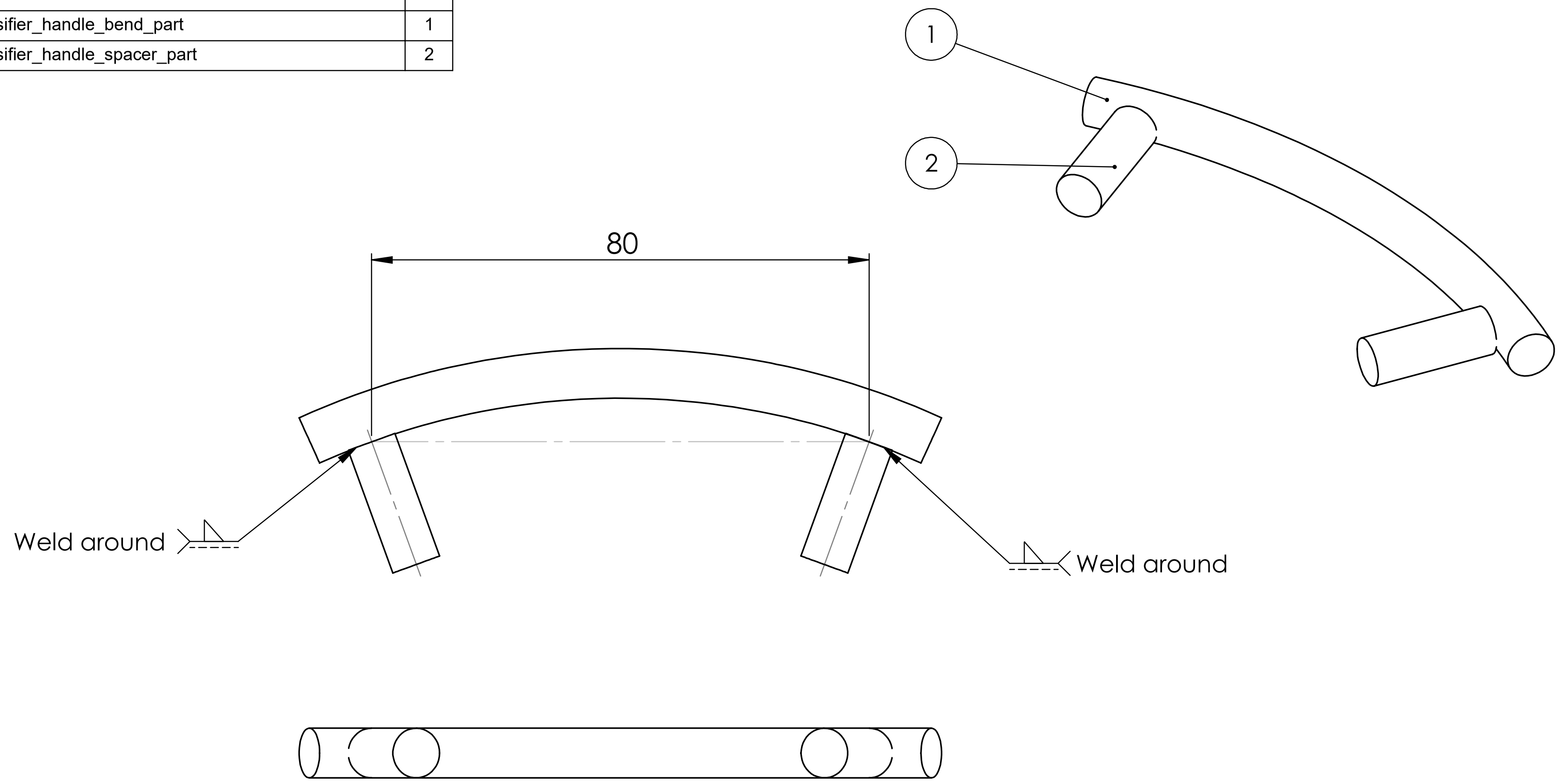




Tag	Direction	Angle	Inner Radius
A	UP	90°	2
B	UP	60°	2
C	UP	30°	2

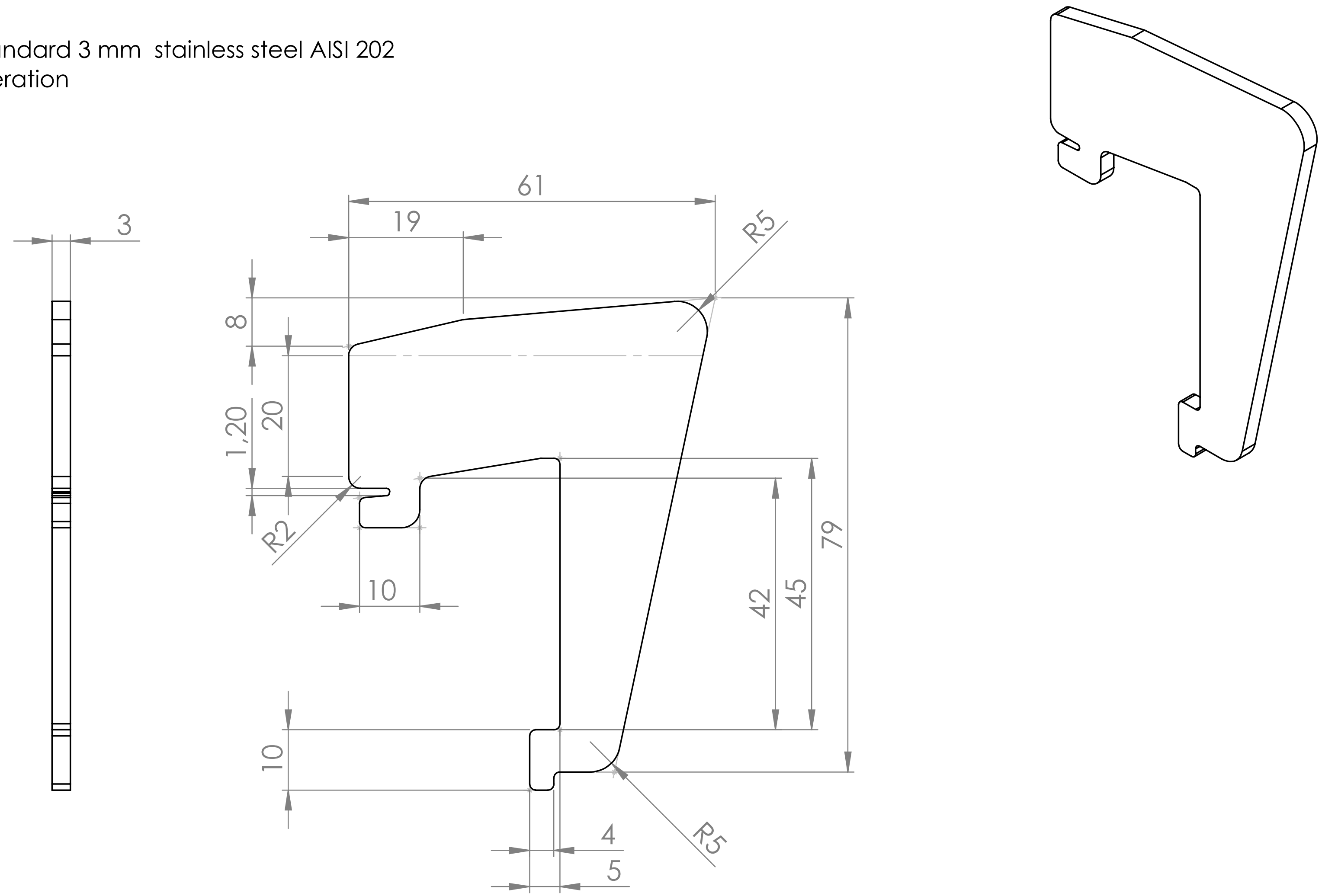
TU Delft Industrial Design Engineering	benaming Gasifier_reactor holder_part_11_DRW	schaal 2:1 getekend <<naam>>	datum 1-4-2016 groep <<groep>>	maateenheid <<maateenheid>> formaat A4 tekeningnummer <<tekeningnummer>>

no	part name	qty
1	Gasifier_handle_bend_part	1
2	Gasifier_handle_spacer_part	2



TU Delft Industrial Design Engineering	benaming Gasifier_handle_ASSEM_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4
		getekend <<naam>>		tekeningnummer <<tekeningnummer>>

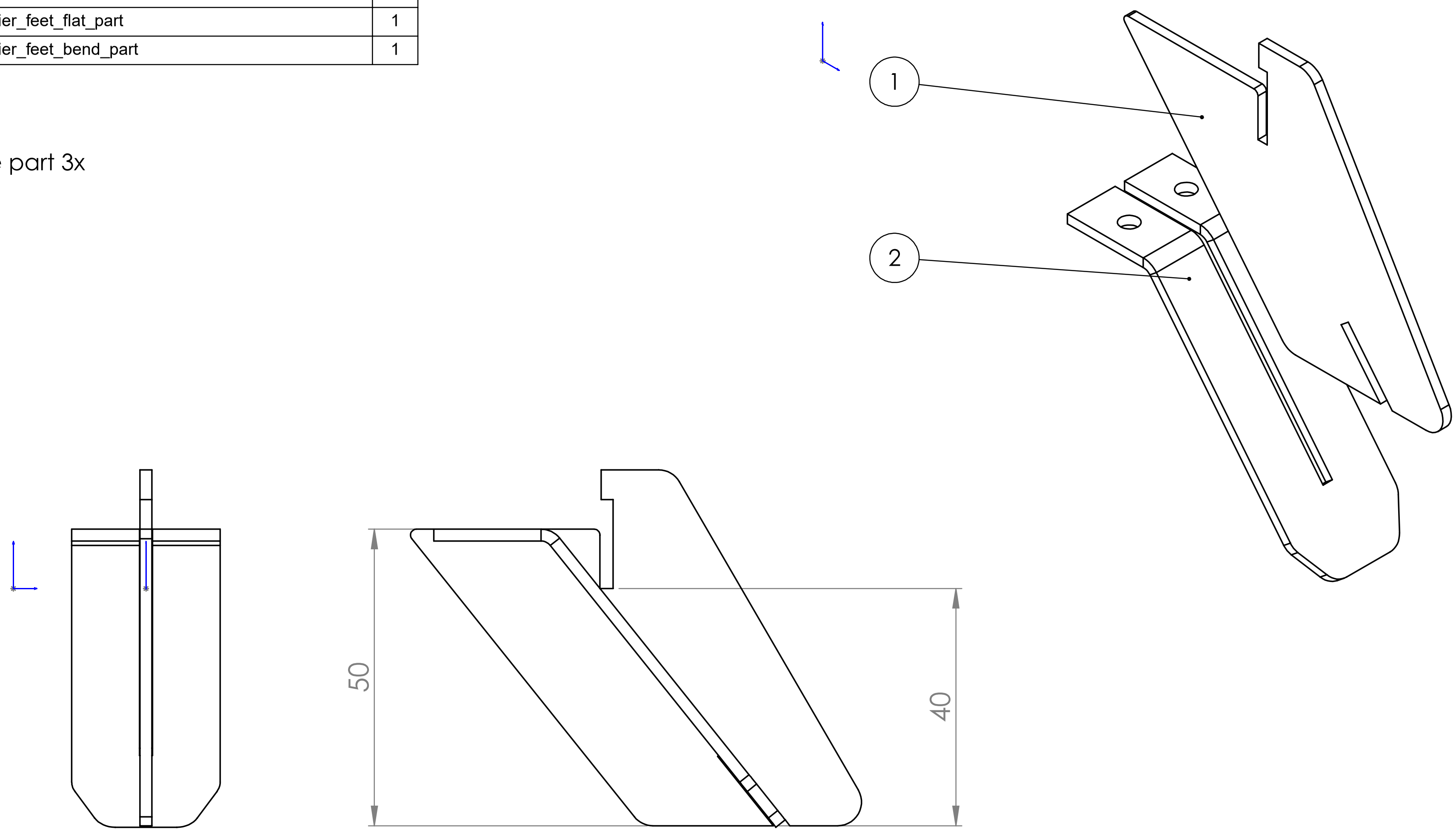
Produce from standard 3 mm stainless steel AISI 202
Use blanking operation
Part number 6
Produce 3X



TU Delft Industrial Design Engineering	benaming Gasifier_pot support 1_part_6_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4	tekeningnummer <<tekeningnummer>>
		getekend <<naam>>			

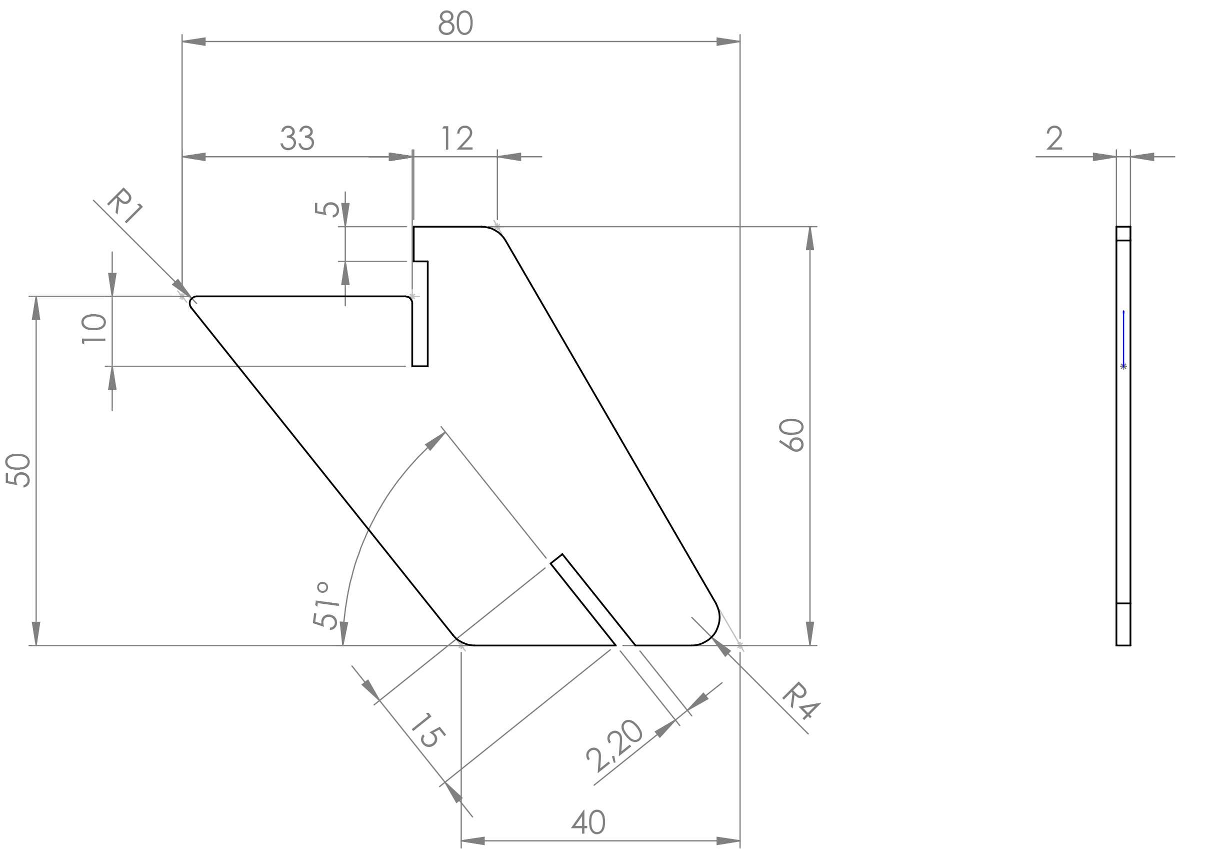
no	part name	qty
1	Gasifier_feet_flat_part	1
2	Gasifier_feet_bend_part	1

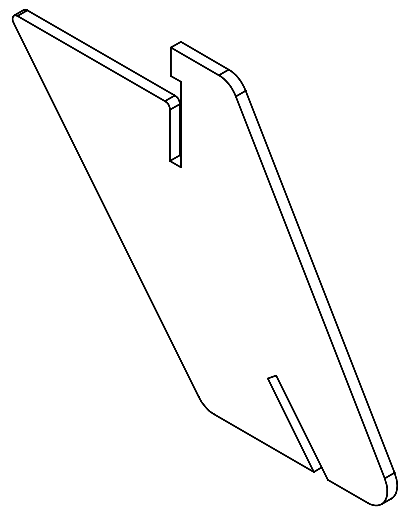
Produce part 3x



TU Delft Industrial Design Engineering	benaming Gasifier_feet_ASSEM_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4
		getekend <<naam>>		tekeningnummer <<tekeningnummer>>

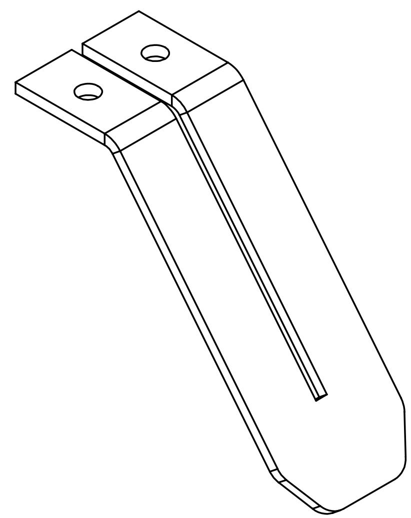
Produce from standard 3 mm stainless steel AISI 202
Use blanking operation
Part number 14
Produce 3X

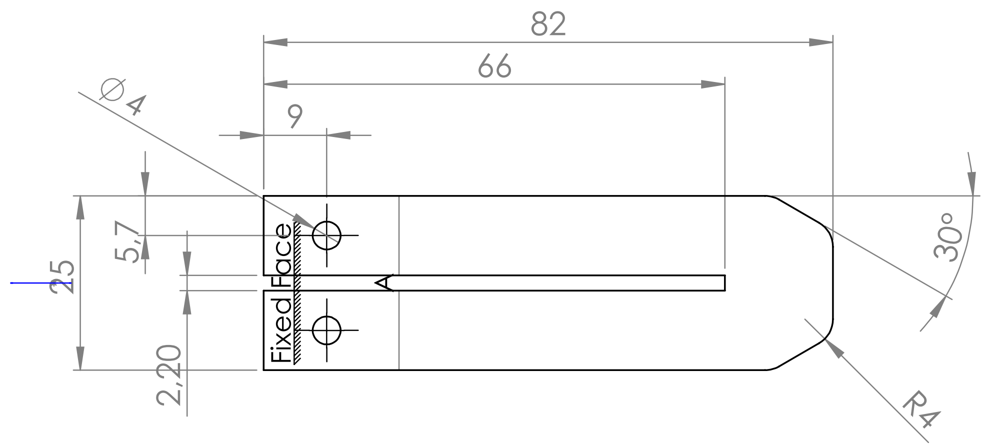




TU Delft Industrial Design Engineering	benaming Gasifier_feet_flat_part_14_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4
		getekend <<naam>>		tekeningnummer <<tekeningnummer>>

Produce from standard 3 mm stainless steel AISI 202
Use fine blanking operation
Part number 15
Produce 3X

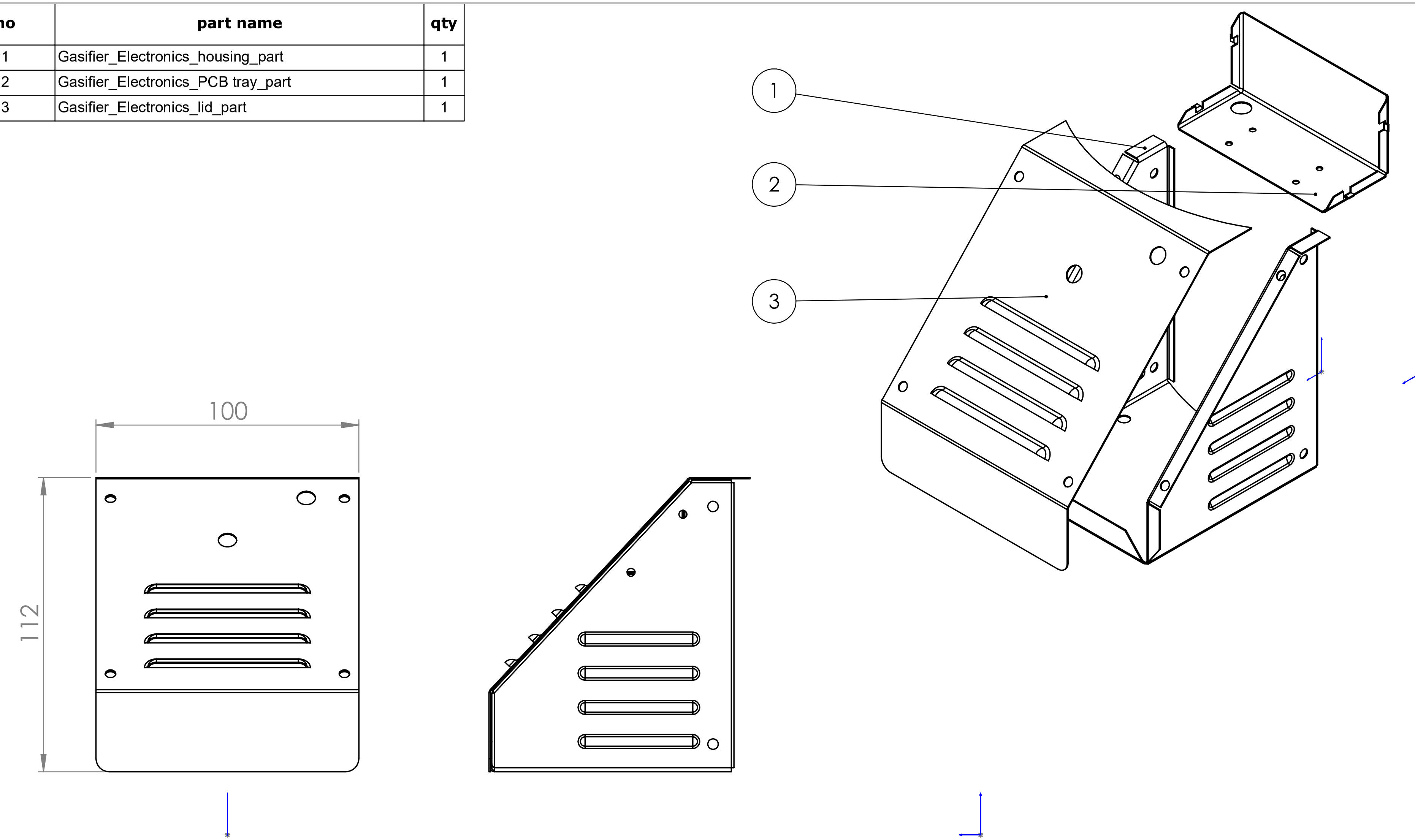




Tag	Direction	Angle	Inner Radius
A	UP	51.34°	2

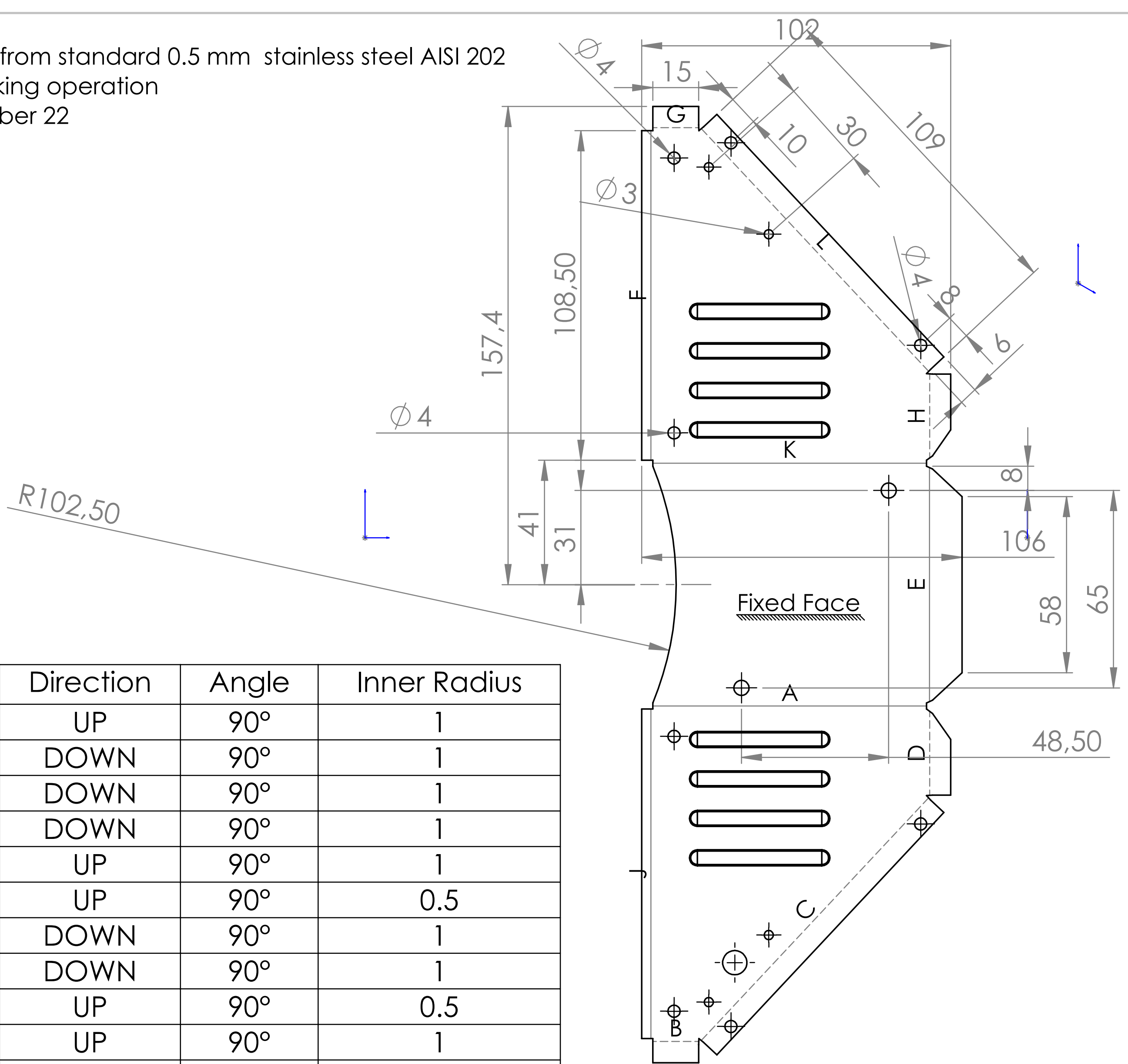
TU Delft Industrial Design Engineering	benaming Gasifier_feet_bend_part_15_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4
		getekend <<naam>>		tekeningnummer <<tekeningnummer>>

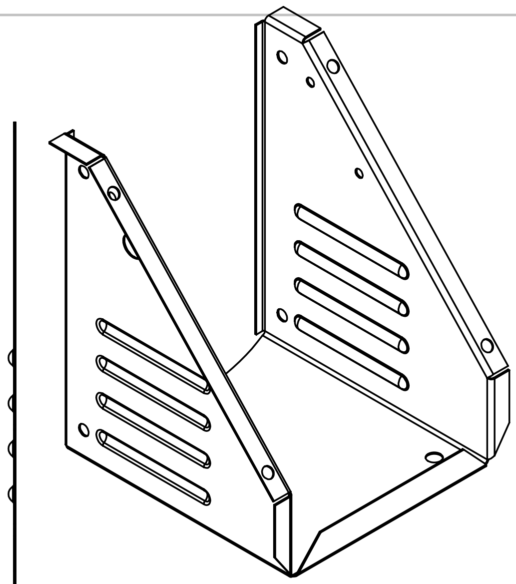
no	part name	qty
1	Gasifier_Electronics_housing_part	1
2	Gasifier_Electronics_PCB tray_part	1
3	Gasifier_Electronics_lid_part	1



TU Delft Industrial Design Engineering	benaming Gasifier_Electronic box_ASSEM_DRW	datum 1-4-2016	maateenheid <<maateenheid>>
	schaal 1:2	groep <<groep>>	formaat A4
	getekend <<naam>>		tekeningnummer <<tekeningnummer>>

Produce from standard 0.5 mm stainless steel AISI 202
Use blanking operation
Part number 22



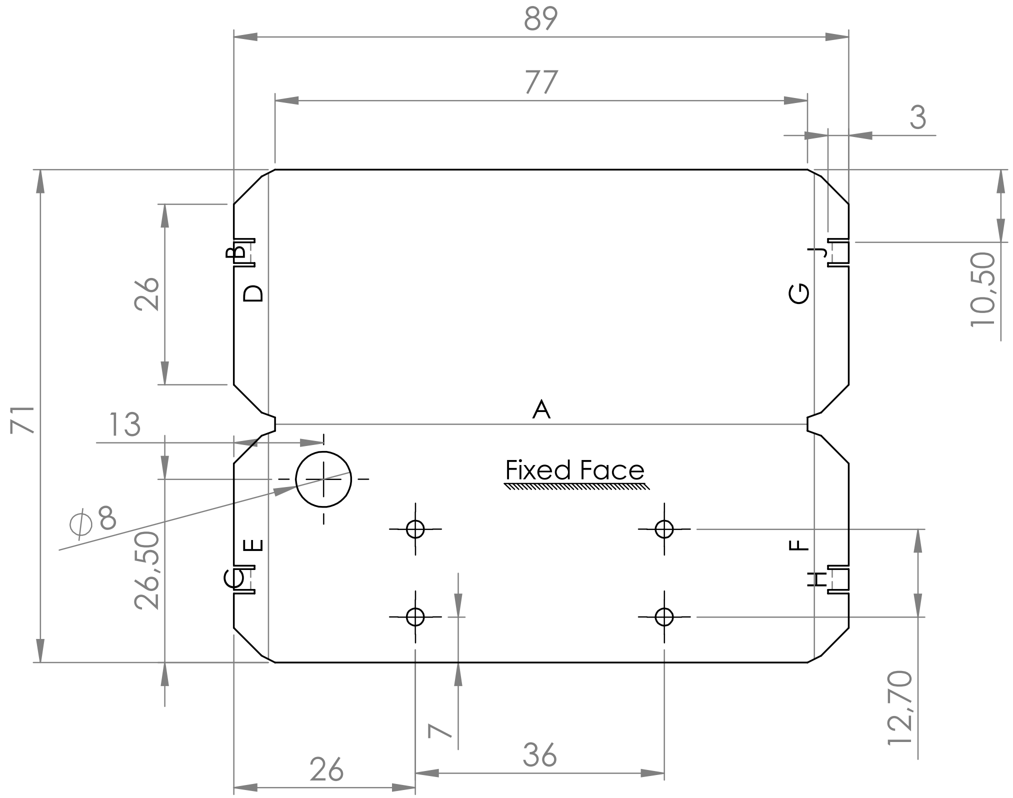


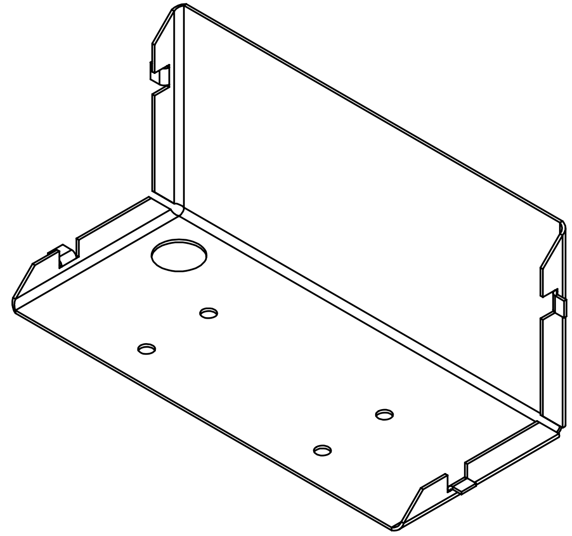
Tag	Direction	Angle	Inner Radius
A	UP	90°	1
B	DOWN	90°	1
C	DOWN	90°	1
D	DOWN	90°	1
E	UP	90°	1
F	UP	90°	0.5
G	DOWN	90°	1
H	DOWN	90°	1
J	UP	90°	0.5
K	UP	90°	1
L	DOWN	90°	1

TU Delft
Industrial Design Engineering

benaming Gasifier_Electronics_housing_part_22_DRW

datum 1-4-2016
maateenheid <<maateenheid>>
schaal 1:2
groep <<groep>>
formaat A4
tekeningnummer <<tekeningnummer>>
getekend <<naam>>



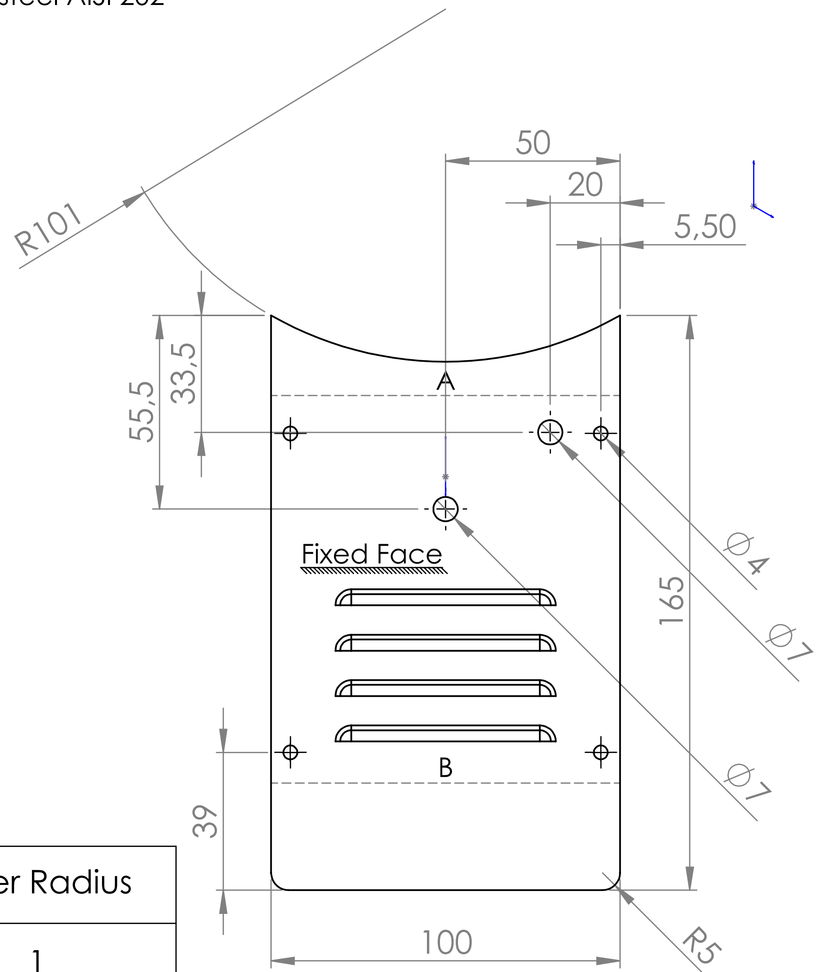


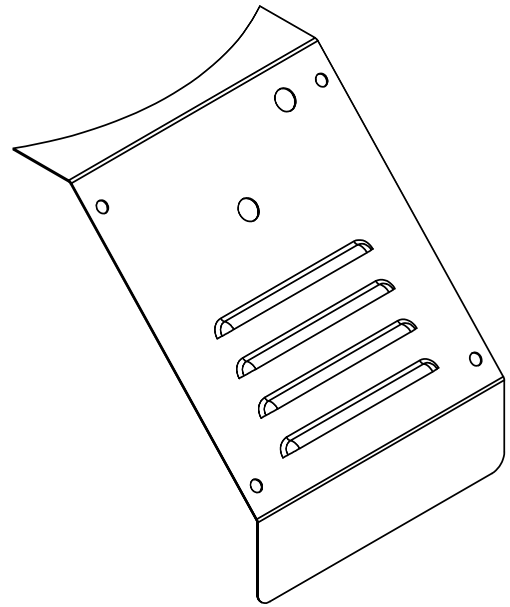
Produce from standard 0.5 mm stainless steel AISI 202
Use blanking operation
Part number 16

Tag	Direction	Angle	Inner Radius
A	UP	90°	1
B	DOWN	90°	0.5
C	DOWN	90°	0.5
D	UP	90°	1
E	UP	90°	1
F	UP	90°	1
G	UP	90°	1
H	DOWN	90°	0.5
J	DOWN	90°	0.5

TU Delft Industrial Design Engineering	benaming Gasifier_Electronics_PCB tray_part_16_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

Produce from standard 0.5 mm stainless steel AISI 202
Use blanking operation
Part number 20

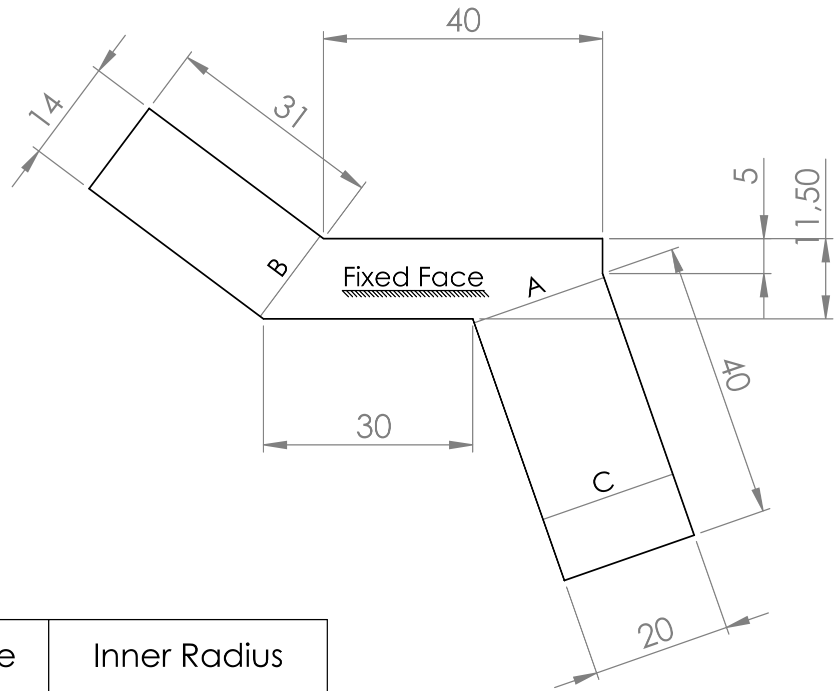


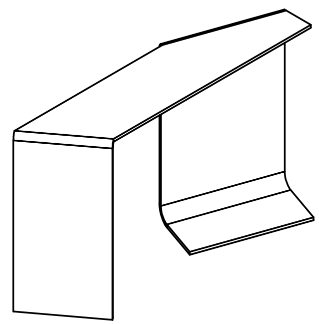


Tag	Direction	Angle	Inner Radius
A	DOWN	46.85°	1
B	DOWN	43.15°	1

TU Delft Industrial Design Engineering	benaming Gasifier_Electronics_lid_part_20_DRW	datum 1-4-2016	maateenheid <<maateenheid>>
	schaal 1:2	groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
	getekend <<naam>>		

Produce from standard 0.5 mm plate stainless steel AISI 302
Use manual bend and cutting operation
Part number 29

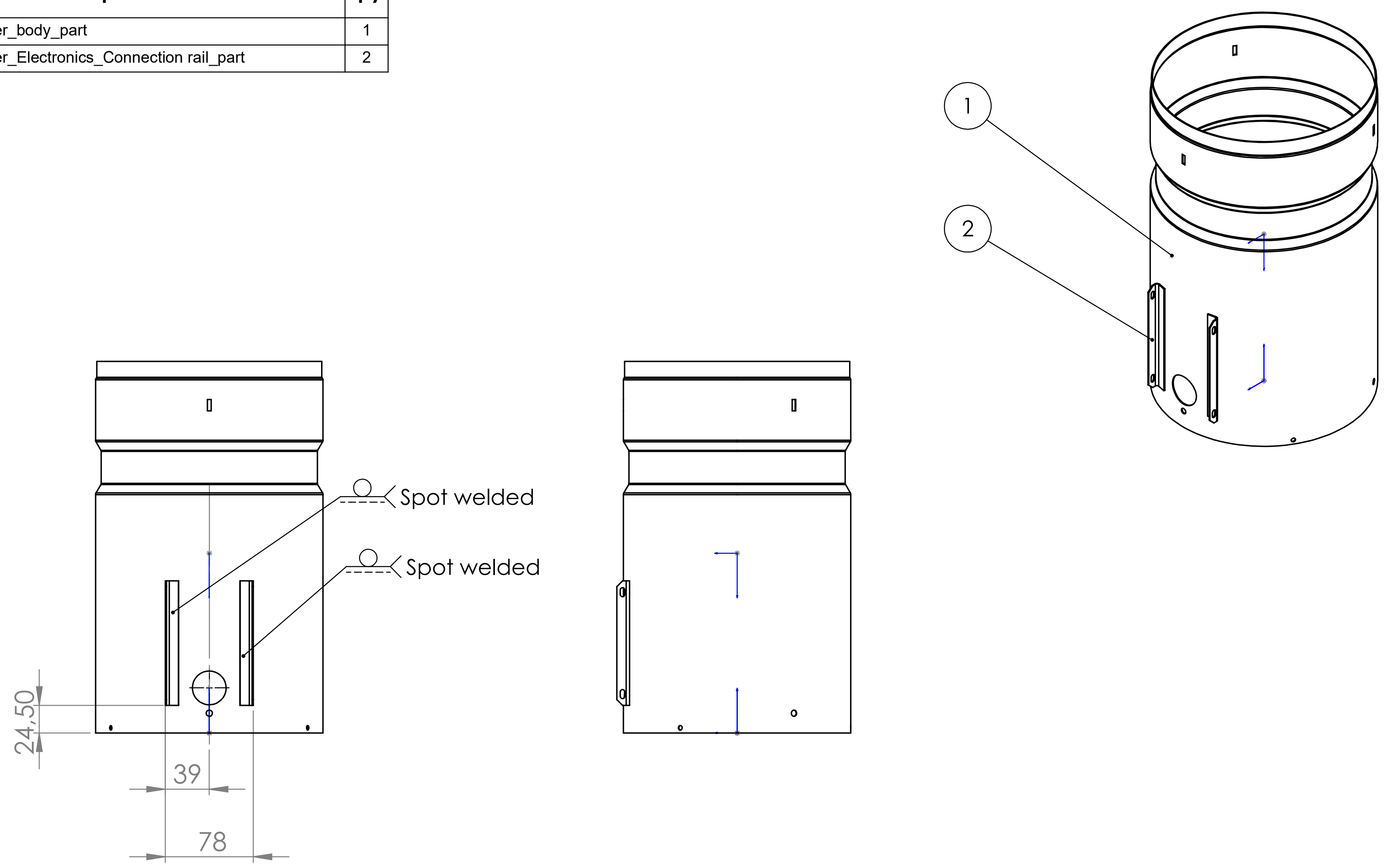




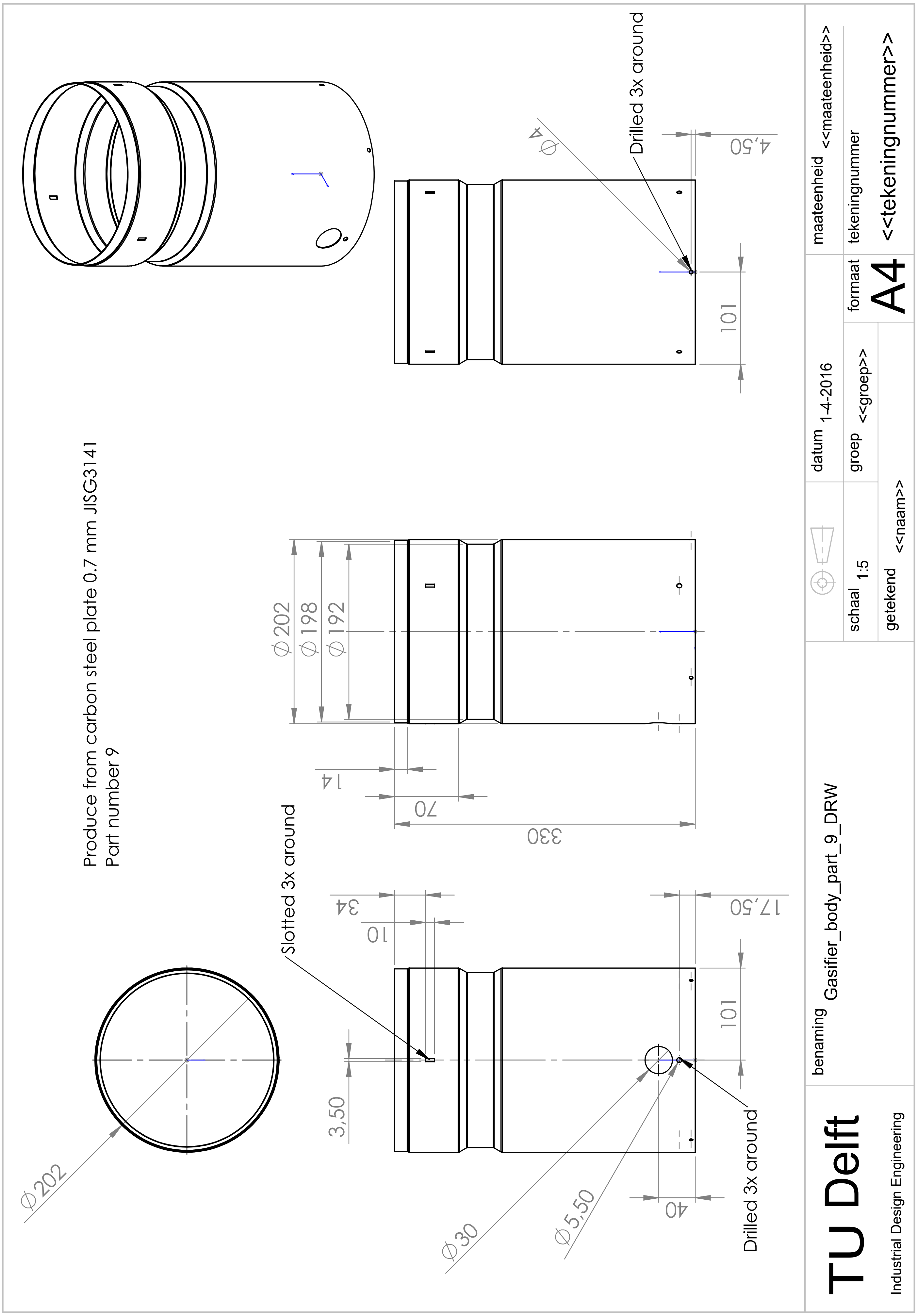
Tag	Direction	Angle	Inner Radius
A	UP	90°	0.5
B	UP	90°	0.5
C	UP	90°	2

TU Delft Industrial Design Engineering	benaming Gasifier_DC Blower_connection_part_29_DRW	schaal 1:1 getekend <<naam>>	datum 1-4-2016 groep <<groep>>	maateenheid <<maateenheid>> formaat A4 tekeningnummer <<tekeningnummer>>

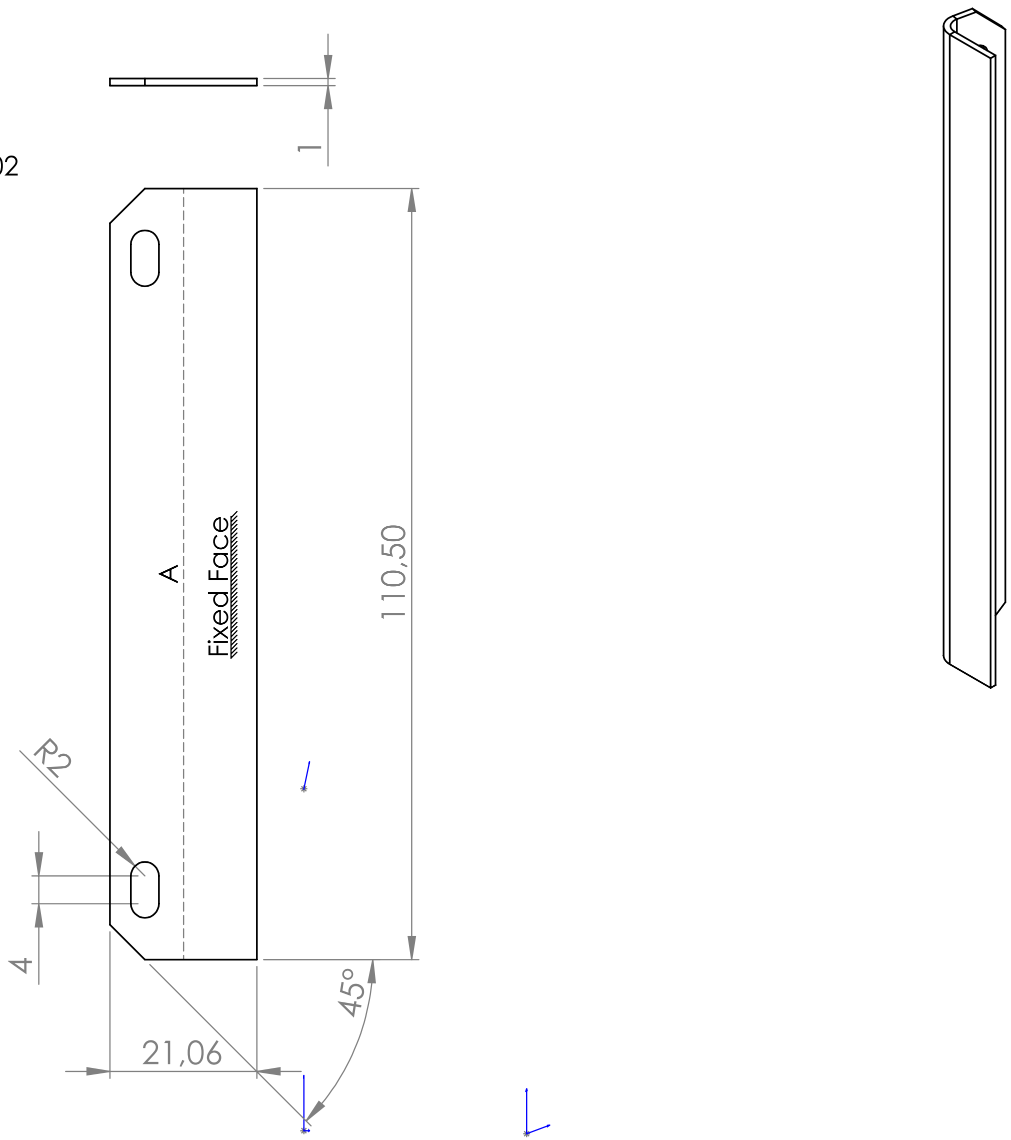
no	part name	qty
1	Gasifier_body_part	1
2	Gasifier_Electronics_Connection rail_part	2



TU Delft Industrial Design Engineering	benaming Gasifier_body_ASSEM_DRW	datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:5 / groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
		getekend <<naam>>	


Produce from carbon steel plate 0.7 mm JISG3141
Part number 9
Drilled 3x around
Slotted 3x around
Drilled 3x around
Ø202
Ø198
Ø192
Ø202
Ø30
Ø5,50
Ø4
4,50
101
101
14
70
330
34
10
17,50
3,50
40
benaming
Gasifier_body_part_9_DRW
TU Delft
Industrial Design Engineering
datum
1-4-2016
schaal
1:5
groep
<<groep>>
getekend
<<naam>>
maateenheid
<<maateenheid>>
tekeningnummer
<<tekeningnummer>>
formaat
A4

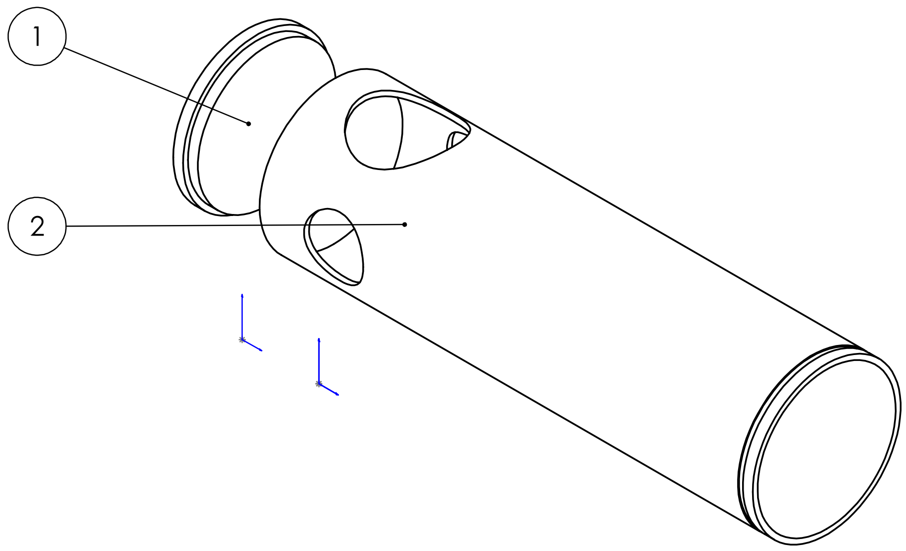
Produce from standard 1 mm plate stainless steel AISI 202
manual bend operation
Part number 23
Produce 2 X

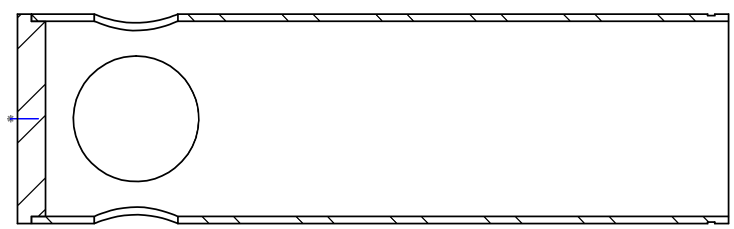


Tag	Direction	Angle	Inner Radius
A	DOWN	101.84°	2

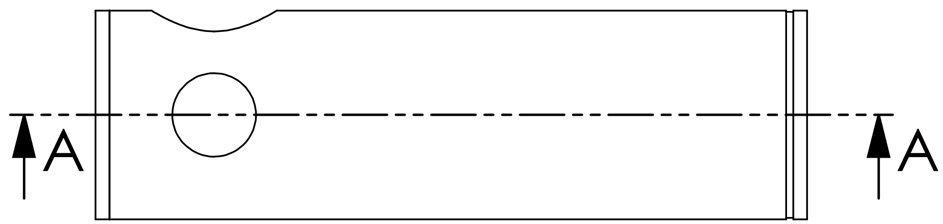
TU Delft Industrial Design Engineering	benaming Gasifier_Electronics_Connection rail_part_23_DRW	datum 1-4-2016	maateenheid <<maateenheid>>
	schaal 1:1	groep <<groep>>	formaat A4
	getekend <<naam>>		tekeningnummer <<tekeningnummer>>

no	part name	qty
1	Gasifier_Air-tube cap_part	1
2	Gasifier_Air tube_part	1



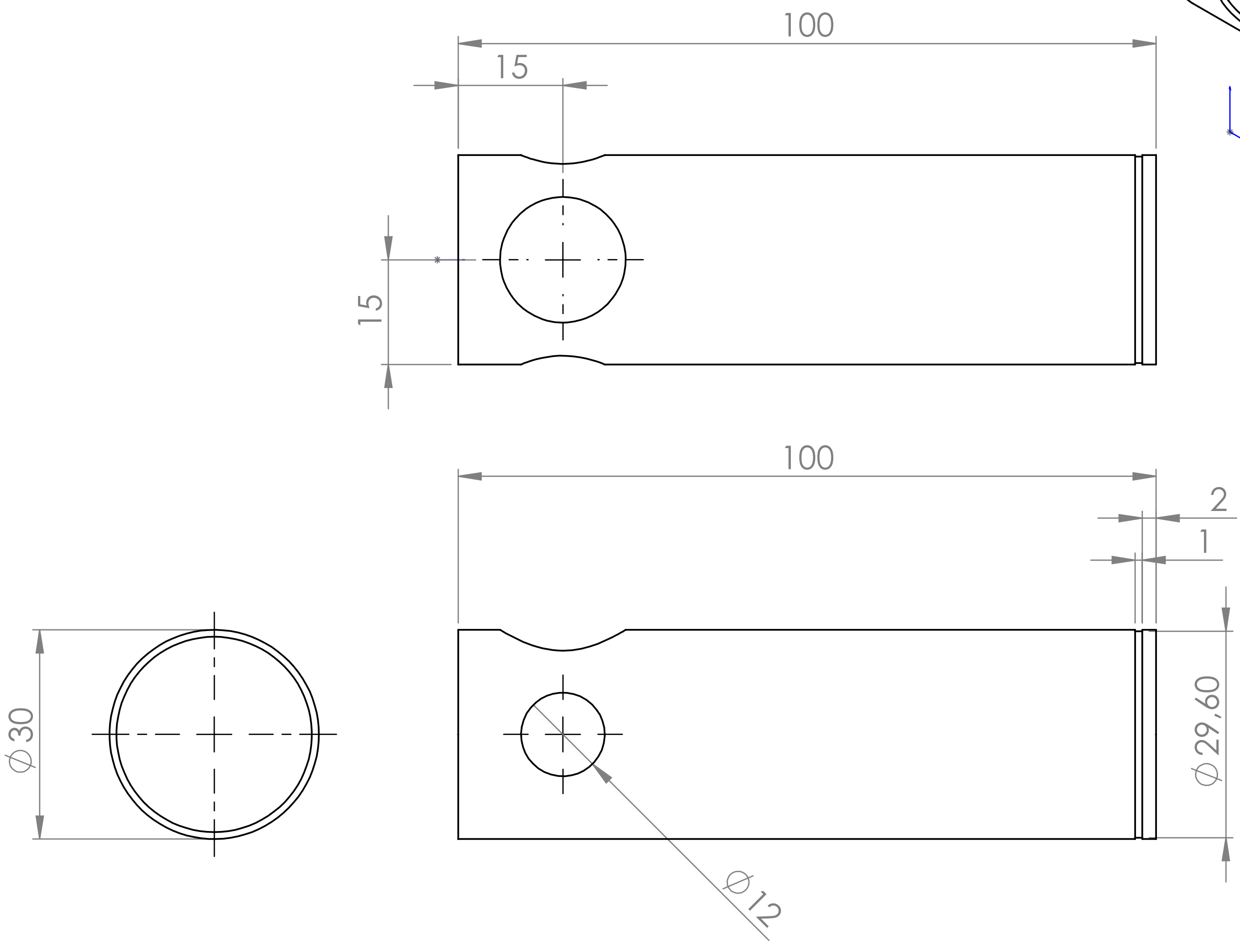


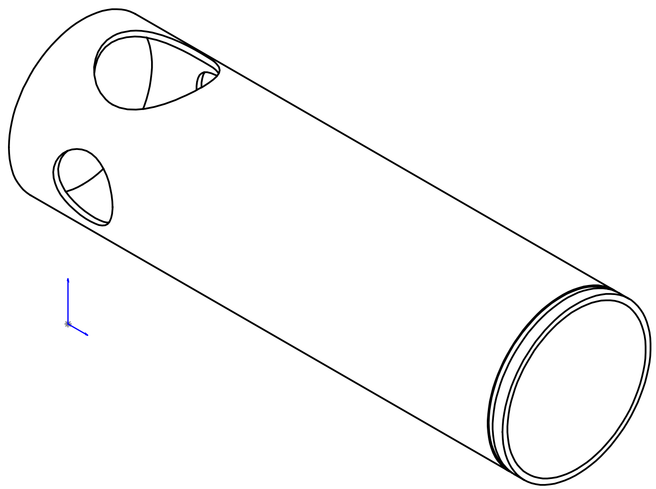
SECTION A-A



TU Delft Industrial Design Engineering	benaming Gasifier_Air-tube_ASSEM_DRW	schaal 1:1	datum 1-4-2016	maateenheid mm
		getekend Pascal	groep CCS	formaat A4
				tekeningnummer <<tekeningnummer>>

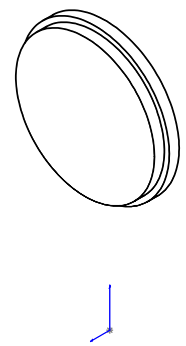
Produce from 1 mm Stainless steel pipe AISI 202
Part nr 24

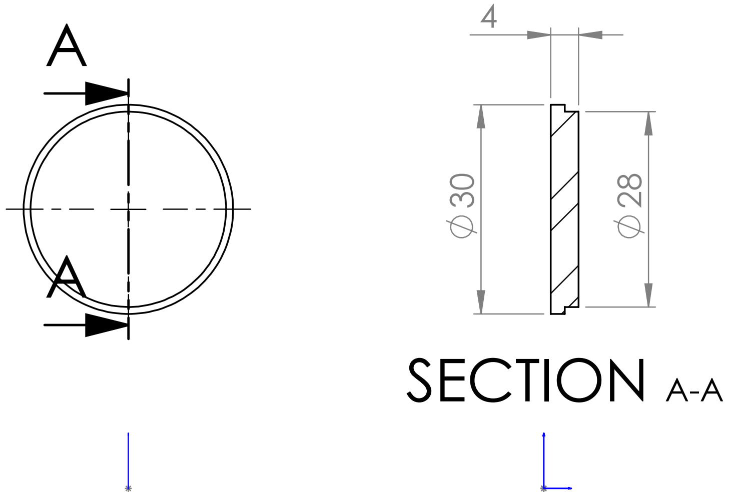




TU Delft Industrial Design Engineering	benaming Gasifier_Air tube_part_24_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4	tekeningnummer <<tekeningnummer>>
		getekend <<naam>>			

Produce from standard 30 mm rod Carbon steel JI SG3141
Use turning machine
Part number 25

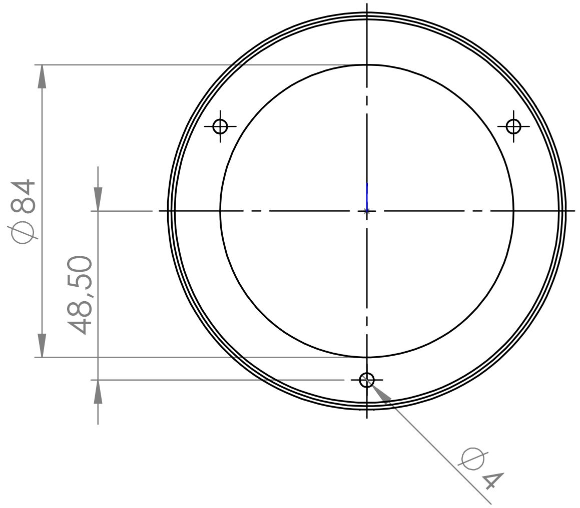


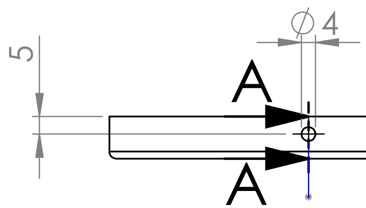


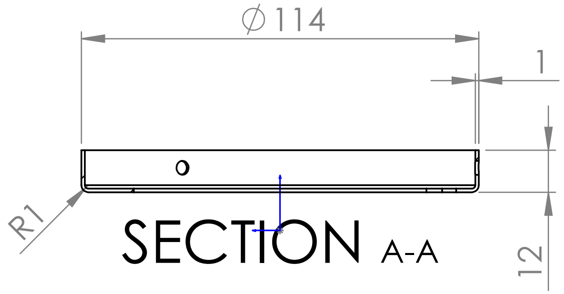
SECTION A-A

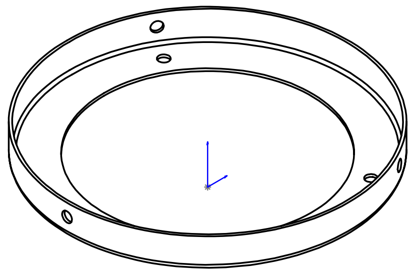
TU Delft Industrial Design Engineering	benaming Gasifier_Air-tube cap_part_25_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:1	groep <<groep>>	formaat A4	tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		

Produce from 1 mm Carbon steel plate JIS G3141
Deep drawing part
Part number 12

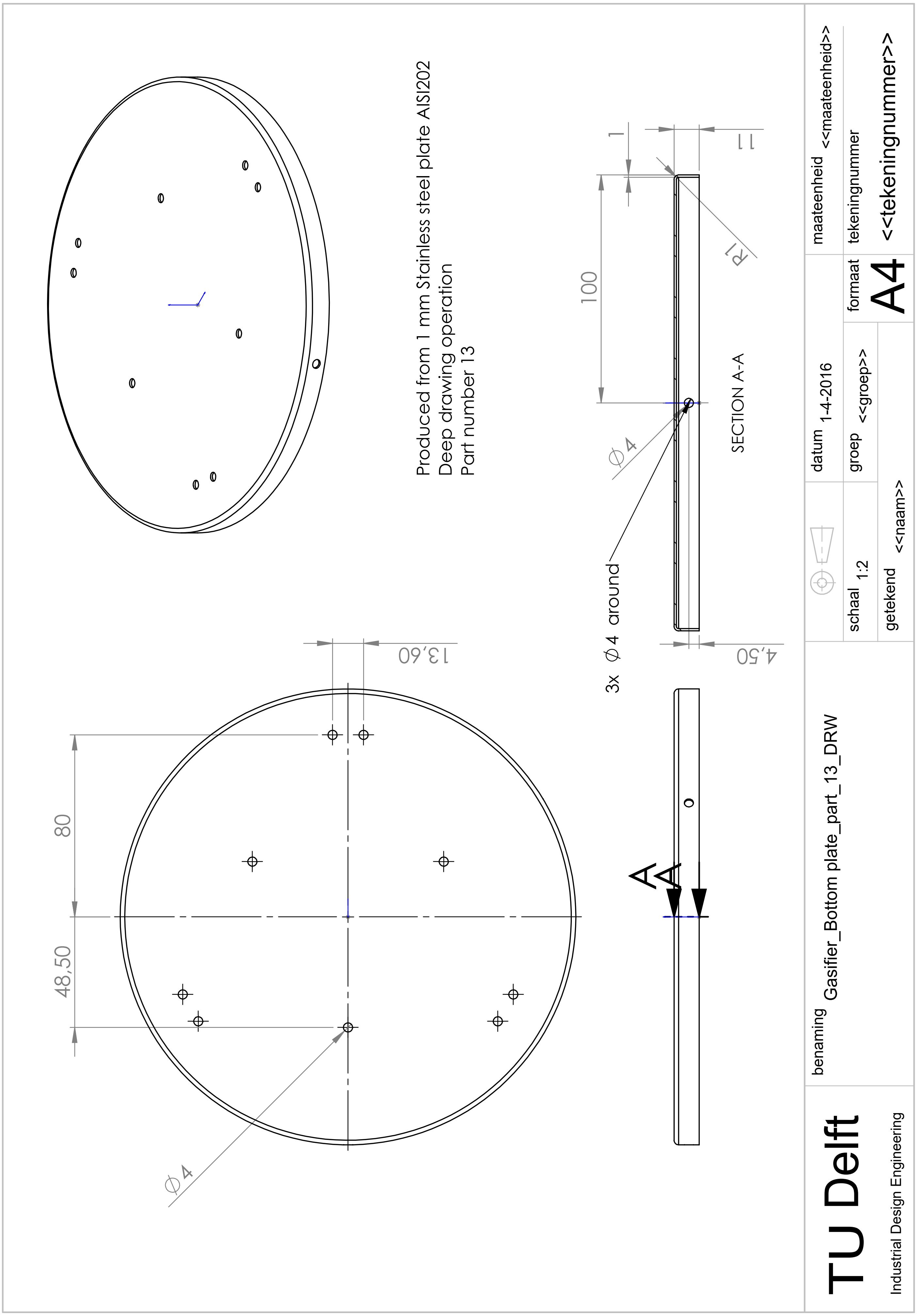








TU Delft Industrial Design Engineering	benaming Gasifier_Bottom connection ring_part_12_DRW		datum 1-4-2016	maateenheid <<maateenheid>>
		schaal 1:2	groep <<groep>>	formaat A4 / tekeningnummer <<tekeningnummer>>
		getekend <<naam>>		


Produced from 1 mm Stainless steel plate AISI202
Deep drawing operation
Part number 13
SECTION A-A
3x ⌀4 around
⌀4
⌀4
100
1
R1
11
4,50
13,60
80
48,50
A
A
TU Delft
Industrial Design Engineering
benaming Gasifier_Bottom plate_part_13_DRW
schaal 1:2
getekend <<naam>>
datum 1-4-2016
groep <<groep>>
formaat A4
maateenheid <<maateenheid>>
tekeningnummer <<tekeningnummer>>

DESIGN OF A BIOMASS MICRO GASIFICATION COOK STOVE

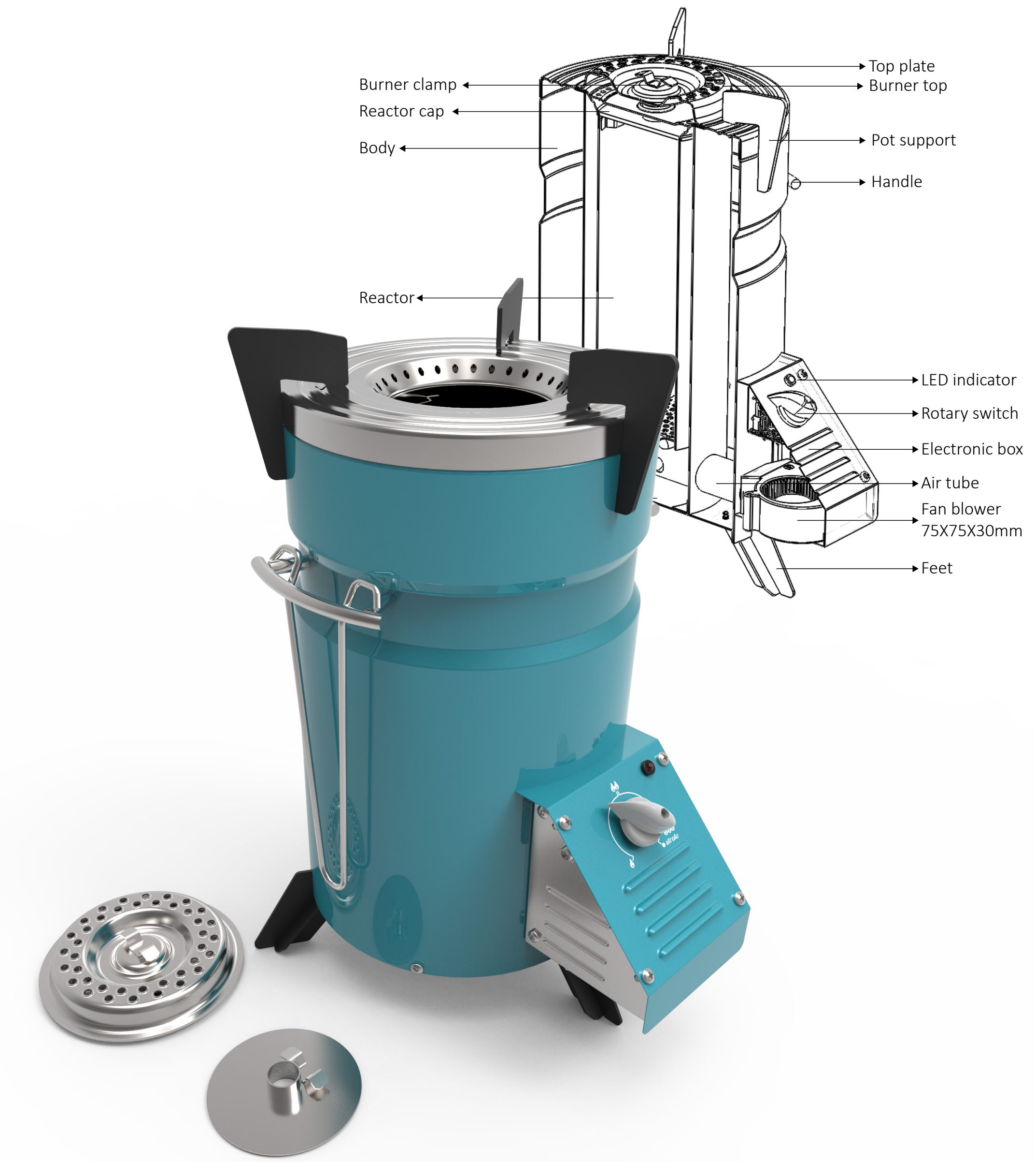
For the households of Vietnam

The problem

Households all over the world, especially in developing countries, still rely on solid biomass fuels for cooking. When used in a traditional manner, high concentrations of harmful emissions can be produced. For many of these users cooking is done inside, in space which are not well ventilated. This is known to be the cause of death of nearly 4,3 million people each year.

The solution

Gasification of biomass for cooking purposes presents a promising solution for several health and environmental issues that occur with traditional methods of cooking. The new design of a gasifier stove has been improved in terms of thermal efficiency. Through testing it was found that the stove can achieve a thermal efficiency of 67%.



Virtually no smoke detected

Less toxic emissions result in fewer deaths and diseases

Reduction in fuel cost less fuel is needed

Reduction in fuel use, with higher efficiency

Faster cooking times, higher temperatures are reached

Pascal Franken
Design of a user friendly, safe and efficient biomass gasifier for Vietnamese households
15-04-2016
Integrated Product Design (IPD)

Committee Dr. ir. J.C. Diehl
Ir. S.G. van de Geer

Company Center for Creativity and Sustainability (CCS)

TUDelft

Faculty of Industrial Design Engineering

Delft University of Technology