CHALMERS

An improved cooking stove for the urban and peri-urban areas in Zambia

Master of Science Thesis in Industrial Design Engineering

FILIP SUNDBLAD

Department of Product and Production Development
Division of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden, 2014

An improved cooking stove for the urban and peri-urban areas in Zambia

Master of sceinece Thesis in Industrial Design Engineering

FILIP SUNDBLAD

Department of Product and Product Development
Division of Design and Human Factors
CHALMERS UNIVERSITY OF TECHNOLOGY
Gothenburg, Sweden 2014

An improved cooking stove for the urban and peri-urban areas in Zambia
FILIP SUNDBLAD

Department of Product and Product Development
Division of Design and Human Factors
Chalmers University of Thechnology
SE-412 96 Gothenburg
Sweden
Telephone + 46 (0)31-772 10 00

Cover: A close view shows the upper part of the improved cooking stove, Hestia, see pages 53-61.

Chalmers Reproservice
Gothenburg, Sweden 2014

Abstract

This master thesis was carried out by Filip Sundblad, master student at the program in Industrial Design Engineering at the department of Product and Production Development, Division Design and Human Factors at Chalmers University of Technology in Gothenburg in cooperation with Vagga till Vagga.

Vagga till Vagga is a small Swedish company which is specialized and foremost proponents of the Cradle to Cradle philosophy and design. The company has started a production of biomass pellets in Zambia to create biochar by using the pellets as solid fuel which can help thousands of users with their daily cooking procedures.

By the design of a new stove for the urban and the peri-urban areas in Zambia aiming to use wood pellets produced from sawdust a better cooking technology becomes available and can be reached by all of those in need. The goal of this project has been to develop and design such a stove with the principle of a top-lid updraft gasifier. A lot of work has been put into making the stove ready for implementation and production.

The final result is a stove for cooking meals in a single pot with the possibility to regulate the primary air supply for better adaptation. The concept is pre-made in modules and packed in flat packages ready for assembly in Zambia with no high demand on expensive and advance machines or tools. The stove provides easy and safe operation for the users with a stable construction.

Preface

This master thesis is a final result of the studies at the Master of Science program in Industrial Design Engineering at Chalmers University of Technology in Gothenburg, Sweden, represented by this report. It was carried out during the spring and autumn 2012 in cooperation with Vagga till Vagga.

I would like to thank my examiner Örjan Söderberg and my supervisor Pontus Wallgren at the department of Product and Production Development, Division of Design and Human Factors for all support and guidance through the project.

Thanks to Per Löfberg and Mattias Ohlson at Vagga till Vagga for all help during the project and who also made this possible.

I would like to thank Tre D Mekaniska and special thanks to Paul Palmqvist who has taken on this project and contributed with valuable inputs.

I would specially like to thank my contact in Zambia, CEO Sonta at EnvrioCo who has helped with both answers and support during the project.

Also, I would like to thank Christa Roth and Paul Andersson, PhD, for all facts and input regarding the technique behind top-lid updraft gasifiers.

Many thanks to all of those people at Chalmers within different departments who have helped me with their special expertise.

Filip Sundblad

Gothenburg 2014

Table of Contents

1. Introduction

1.1 Background

Today in the urban countries the growth of the population is higher than it has ever been before with consequences on both food supply and suitable area to live in. The growth has led to deforestation as the population cut down the forest to gain areas for agriculture, lifestock and biofeul production both for their own use and for export. The most common fuel for heating and cooking in the urban countries is wood or charcoal, with inefficient charcoal production where people in principle grow up forest and then burn it down, which contribute to the deforestation. With problems of poor ventilation and too solid built houses the urban populations suffer from toxin poisoning due to the social behavior or habit of cooking indoors.

Vagga till Vagga (see part 1.1.1) is now leading a project where the purpose is to shift wood and charcoal to pellets from biomass waste to use in micro-gasification stoves. This is done to decrease the deforestation in the area and stop leaching of the soil. An added benefit is that people don´t need to buy expensive fuel or use big part of their time to travel long distances to collect wood. Another benefit of this type of micro-gasification stoves is that it does not pollut the air with hazardous particles. This could save about 2 million people who every year die of smoke related injuries. This technique also contributes to the production of biochar which locks the carbon dioxide into the soil where it contributes to better growth.

1.1.1 Companies involved

Vagga till Vagga is a small Swedish consultancy agency that strives to create a better future by healthy material flows and eco-effective solutions. They are independent from Cradle to Cradle (C2C) and EPEA (Environmental Protection Encouragement Agency) but still satellite-partners, a small office in a different location from a company or government agency´s main office. able to give C2C certifications (EPEA, 2013). Vagga till Vagga is the foremost proponents of Cradle to Cradle philosophy and design in Sweden. Their work areas are within both the principles of cradle to cradle philosophy and biochar. The fundamental idea behind the concept C2C is that materials circulates in close loops where the quality level of them remains and can be reused to create prosperity. When this is not longer possible the nutrients are safetly returned to the biosphere. EPEA works with helping implementation of the C2C -methodology for clients worldwide designing new processes, products and services.

Figure 1. The Vagga till Vagga logo.

Tre D Mekaniska AB is a modern mechanical workshop with different kinds of skills within steel, stainless steel and aluminum processing. They work primarily with laser cutting in 2D and 3D as well as with tube laser technology together with further refines as press brake, welding, machining and surface treatment. The company was started in 2003 by five persons with earlier and broad experience within the industry.

Figure 2. The Tre D Mekaniska logo.

Tre D Mekaniska was contacted by Vagga till Vagga in the beginning of the project to assist with knowledge and performance of processing the physical product. The purpose with this was that they should be the partners who produced the stoves in the end. The funding of the manufacturing and the materials was also supposed to be supported by the company together with the municipality.

1.2 Purpose

The purpose of this project is to design a new stove for the urban and the peri-urban areas in Zambia to help them with better cooking technology in every day situations. This is going to contribute to better health and environment for the people who live there. Another important part for the project is the social and sustainable development with cradle to cradle principles as a foundation but also to look into different applications that the stove can have to simplify the usage for the target group. The purpose is also to support the ability to reuse the material afterward for the urban people and to extend the life of the material by making it easier to disassemble. The three main purpose of this project are.

- Facilitate the cooking situation.
- Facilitate introduction of biomass gasifiers in Zambia.
- Facilitate to better health and a better environment.

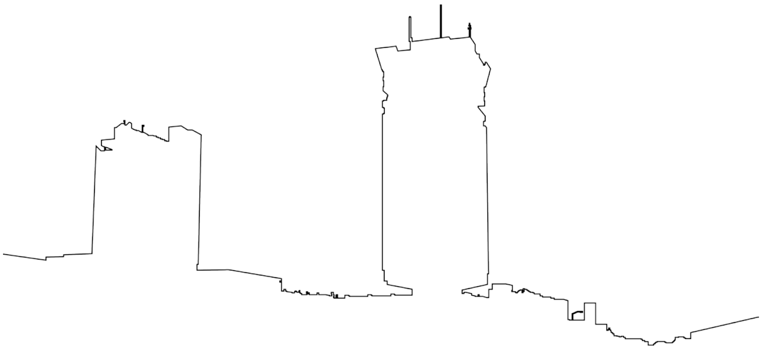
1.3 Aim

The aim of this project is to develop and design a new stove with the principle the top-lid updraft gasifier uses (see page 21) which uses pellets as solid fuel produced from biomass waste like sawdust. The whole project should end in a prototype aimed as production basis for production of 500 units in the end for sale rather than a form concept. The aim is also to prepare the product for production in Sweden, transportation and assembly in Zambia, either by the households themselves or by a local workshop at site depending on the circumstances of the solution. Another important aim with this project is to create a deliberate user impression which should be conveyed by the end solution.

1.4 Delimitations

The target group within the project will be limited to only focus on users in Zambia who already today buys fuel and stoves to provide food for their households. Make the product adapt to the precondition of the life situation in Zambia. No deeper effort will be spent on research in which type of fuel is aimed to be used for the stove. The package design for the transport will not be considered in this project. Work is based on cradle to cradles principles.

2. Theory



A Literature study was performed to collect data and facts regarding the country. This method has the advantage that it´s easy to pursue, it can be done by physical resources or on the internet but also in verbal form all to supplement the collection of relevant information.

Figure 3. Map of Zambia

2.1 Zambia

Zambia is placed in the middle part of south Africa shortly under the equator. The country neighbors to eight different countries from Angola in West, Democratic republic of Congo, Tanzania in North, Malawi in East and Mozambique, Namibia, Botswana and Zimbabwe in South. The climate in Zambia is due to its tropical placement in Africa mostly subtropical because its height over the sea level. In Zambia there lives around 13,8 million people today (CIA, 2012) on an area almost as big as France and United Kingdom together. The people are split in seven main tribes and a collection of 75 smaller tribes and speak equally as many languages. The biggest and official language is English due to the country´s historical heritage as an English colony (Countries and Their Cultures, 2012).

2.1.1 Living

The majority of the people in Zambia live in either rectangular houses made of burnt bricks or in round house where the construction can differ from using branches and weaving technique or branches covered in dried mud with metal roof or more prevalent roof of poles and thatch. The choice of building technique is based on tribes' customs, on settlers or on missionaries using the western standards when they colonized the land (Countries and Their Cultures, 2012). A common household consists of two or three rooms with one bedroom. In the urban areas it´s only 50 percent of the houses that are owned by one or several of the members in the household the rest is owned by the state, NGO´s or other private investors (Republic of Zambia Central Statistical Office, 2000).

Figure 4. One typical house in the peri-urban countries.


Figure 5. Zambian preparing food.

2.1.2 The cooking habits

The base of Zambian cooking is the Mealie meal in which the main ingredient is maize corn and which has a consistency as thickened mashed potatoes. To this they serve a small dish by the side of the main course called relish. The Mealie meal is served three times a day, at breakfast as porridge and as Nshima at lunch and at dinner. The relish is usually made from goat meat, fish, chicken or vegetables and served to add some flavor and variation to the course. In the poor areas where meat is not something that people can afford every day Nshima is served with beans, dried fish or vegetables (M. S. Tembo, 2012). The dishes are most commonly prepared with charcoal stoves or improved charcoal stoves. People tend to use more charcoal as fuel for the stoves in the city and wood in rural areas which are produced from indigenous woodlands on the countryside. The actual cooking is prepared and done mainly by mothers and housewives outside sitting down with the stove between their legs. One meal can take up to 3 to 4 hour to prepare, in this case it´s beans which take a long time to cook. If they cook indoors it´s often to take care of the heat that is produced by the stove to warm up the house at night. A common pot in Zambian households used for cooking is a thin round bottom aluminum pot that can contain five to seven liters of liquid. The size of the pots they use are varying in diameter from at least 120 mm up to 240 mm where the common sizes are between 150 mm and 220 mm (P. Löfberg, and M. Olsson, 2012).

To better understand the conditions under which the people live in and how they use their stoves two semi structured interviews were done with one person who lives in Zambia (see page 81) and another who works with implementations of improved cookstove programs. Semi structured interviews means that a questionnaire with Open-end questions is used during the sessions. This gives a rich qualitative amount of data in the field instead of quantitative. The person who lives in Zambia informed that after the stove´s lifespan is reached the house holds throw them away in most cases and the existing recycle possibbilities are limited. There are material dealers that can give some payment for the material if the stove is recycled. The stoves are seen as a kind of status symbol for the households in the society, so a fine stove gives a kind of sentimental value for the individual households, where corrosion resistance can be one thing that makes the stove considered a finer stove (S. Kauti, 2012).

2.1.3 Base economy

Today Zambia is one of the most urbanized countries in Africa with a current situation where one fifth of the people lives by the Copperbelt up in north. The majority lives in the city of Lusaka where more than two million people live. It´s estimated that 43 percent of the population live in cities. Most residents of Zambia are farmers, especially the urban population which live mainly of low-yielding subsistence farming (Countries and Their Cultures, 2012). The income for a common family member in the urban areas is 1 to 3 USD per day which should cover all their expenses. One of the important expenses a household has is fuel for cooking which in the case of charcoal cost from about 181 USD to 342 USD for one year (Sep 2012) depending on the size of the household and where they live (P. Löfberg, and M. Olsson, 2012).

2.2 Health

Today about 2 million people around the world dies of smoke related injuries from indoor air pollution every year and most of them are children and women. The problem is directly related to the inefficient and poorly ventilated stove that they are using for cooking with biomass fuel. The only factors that contribute more to the negative global health is unsafe water and sanitation problems. There are more people who die from indoor air pollution each year than persons that die from malaria and tuberculosis together. The pollution from burning solid biomass contribute to a high risk of evolving pneumonia among children and chronic respiratory diseases among adults where pneumonia alone kills nearly 900 000 children every year.

Another common injury related to ordinary cooking chores is burns were most victims are children. Burn related deaths among infants is three times higher in the regions of Africa than in the rest of the world. It´s estimated that about 300 000 people over the whole world die from burn related accidents every year. These accidents often happen because the children are playing in the same room as the stove is placed and get the pot with hot liquid over themselves. A common situation for many households especially in poor ones are that they only consists of one room where they place the stove directly on the ground (WHO, 2012).

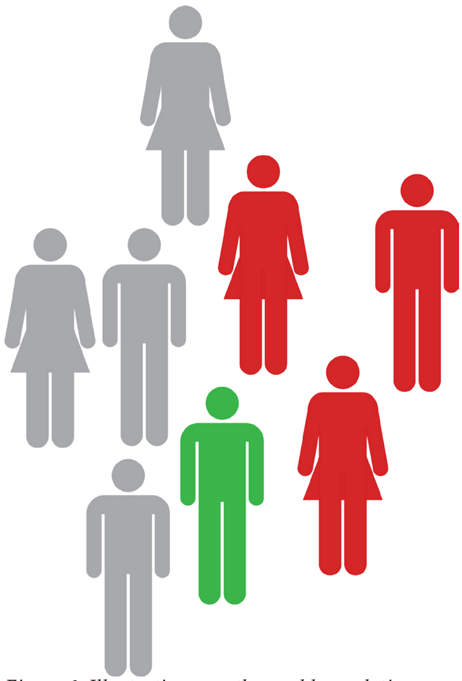


Figure 6. Illustration over the world population showing how many people who are using biomass, red nad green, and how many who are directly dependent, red.

2.3 Environment

There is more than 50 percent of the earth´s population (52%) that are using biomass and coal for cooking and heating. In this group of the world´s population it has been estimated that more than 2,7 billion people are directly dependent upon biomass as fuel for heating and cooking (see figure 6). This is especially the case among the poor people where as much as 95 % is relying on solid fuels to meet their needs. The need for and dependency on solid biomass as fuel for households increases and exacerbates deforestation in the world which leads to higher levels of carbon dioxide and black carbon in the atmosphere with an accumulating rate of greenhouse gases. Deforestation can even affect the nature at local level by soil erosion, loss of biodiversity and pollution of streams. Since more forest and bushes being cut down it gets harder to find wood which forces people to spend more and more time to collect biomass for fuel and to walk further and further away to succeed with the task. The burning of solid fuel in open fires and the unburned smoke emitted during the process are estimated to stand for 18% of all greenhouse gases (WHO, 2012).

2.3.1 Biochar

The name Biochar refers to a fine-grained and highly porous charcoal obtain from carbonization of biomass which easily can absorb water and nutrients and is used to restore dry and nutrient deficient soils by adding char to it. The char keeps the moisture in the ground, increases the fertility and agricultural productivity. In the same way it improves the water quality and quantity by increasing the retention of nutrients and agrochemicals for plants and crop utilization in the soil. The nutrients stay in the soil and are kept from causing pollution by leaching into the ground water. Biochar can also protect against certain forms of foliar and soil-borne diseases. It also returns carbon from the atmosphere back to the ground stock and lock it up. In this way the biochar reduces the pressure from the forest as long term carbon sequestration. A Swedish research done in 2010 shows that crops increase their production with 30 percent when biochar is used compared to when no biochar was added. The experiment was done with sandy soil which is the case in generally for the urban and peri-urban areas in Zambia. With biochar the system of using biomass as renewable energy and then putting the biochar back into the ground can be ”carbon negative”(it doesn´t contribute to the increasing amount of carbon in the atmosphere) (Vagga till Vagga, 2012) (International Biochar Initiaive, 2012).

2.4 Gasification of wood

The gasification of wood works similarly to how a classic candle burns with a multi-step process which starts as soon as the candle is lit with slowly melting the wax. The wax travels along the wick as liquid to the end and vaporizes into the air by the additional heat from the wick. At the other end, the created heat from the flame melt the solid wax at the top of the candle by both radiant heat and proximity heat and the vaporized wax mixes with the oxygen in the air and creates a visible flame where the vaporized wax leave the wick and contacts with the oxygen surrounding the flame.

In the same way as candles burn the wood burns with different steps of transformations closely proximity but with small difference in time and space. Every step leads to a reduction of the solid mass and volume of the fuel due to vapors and gases that are released. During this process temperature rises from ambient to above 800° celsius depending on the surrounding conditions. If the combustion succeed to be completed no emissions are created and vaporized into the air and only clean air remains, containing carbon dioxide and steam. On the other hand if the combustion is not complete combustion then smoke and unburned fuel with carbon monoxide will be spread in to the air as a result. To achieve an efficient combustion the preferred temperature lies between 800 and 900 degrees celsius in a industrial incineration process (World Bioenergy 2012, 2012).

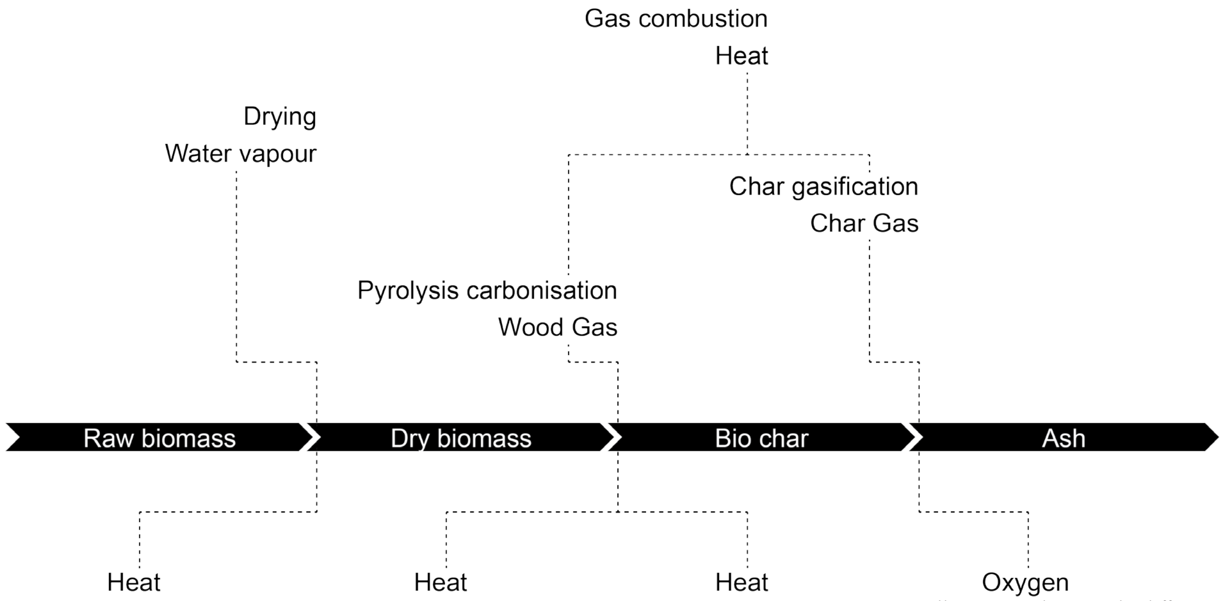


Figure 7. Illustration showing the different steps within the combustion process.

What happens in each step during the combustion process is that the fuel first start to dry, when the water transforms to vapor. Depending on how big amount of moisture content it is in the raw material. This is also related to the heat input that is needed to dry the fuel from the water content and reduce the mass and volume of the material. Next step is the pyrolysis phase when the heat increases due to the temperature rises and decomposition of the biomass to solid char occurs due to the material turns into volatile gases and vapors. The term ”wood-gas” refers to the contents of different carbon-compounds with fuel value within the vapors. This phase also can be referred as ”Carbonization” because of the solid char that is an outcome of the pyrolysis. The pyrolysis can progress with total absence of oxygen. The only thing that affects the process is the heat input so without heat: no fire and no biomass combustion. From solid char to conversion of carbon atoms to gases and non-carbon to ash is the char-gasification stage which only can occur if there is enough amount of oxygen available to react with while it´s hot enough. What happens is that the oxygen reacts with the solid char and emits carbon-monoxide, carbon-dioxide and additional thermal energy. The char that is not emitted remains as ash consisting of non-burnable solid minerals. This phase is controlled by the amount of available oxygen and the presence of heat near the char. If there is little oxygen and/or not hot enough the conversion of char to ash is omitted and the char stays intact as char without any transmission to ash. Gas-combustion is the last step in the combustion process chain. Here the hot ”wood-gas” is burnt and the released heat can be used for different purposes. This combustion process is dependent on that there is sufficient amount of oxygen available because it´s need to be the right mix of gases, vapor and oxygen for the reaction to be able to ignite due to that combustion is only a chain of oxidization reactions. The result of not enough available oxygen during the oxidization reactions leads to that the gases will not be burnt and unburnt smoke and carbon monoxide will be released into the air resulting in incomplete combustion process. When the combustion is complete the flame is the visible indicator of a successful reaction where the only gases that leave the process is the fully oxidized ones. The aim is that all hydrocarbons from the biomass have been burnt and transmitted to carbon dioxide and water vapor. For humans that stays in areas with incomplete combustion the vapor and gases converts to undesirable emissions where the wood-gas is irritating smoke noticeable for the eye and the char-gas on the other hand is an odorless, imperceptible and toxic gas for human where the carbon monoxide is both poisonous and dangerous for human health.

If only looking at the energy flow of the biomass combustion the two stages of drying and pyrolysis are endothermic meaning that they need energy to break the chemical bonds between the atoms in the solid fuel which leads to that this stages actually exhaust heat to progress. Before the heat from the combustion reaction can supply with enough thermal energy by itself to keep the fire going it needs an external heat source to ignite the fire. To control the process it´s significant to understand that the first two steps are controlled by the heat input that reaches the solid biomass. This can be compared to the two later steps, char-gasification and gas-combustion, where the amount of available oxygen is the crucial element to control (giz HERA - Poverty-oriented Basic Energy Service, 2011).

2.4.1 Biomass gasifier

The biomass gasifier is in contrast to a traditional open fire a general term for a unit that convert solid biomass into gas which in the next step can be burnt under controlled conditions. The difference between an open fire and a gasifier is that with an open fire the combustion process is controlled by the asset of firewood compared with an gasifier were it´s the asset of air. Another aspect of an gasifier is that the gas generation phase and the gas combustion phase occurs separate in space and time. The expression "biochar making pyrolytic gasifier" refers to the char gasification phase which does not receive enough air. The char is conserved from the pyrolysis due to the sufficient air which generate the combustible gases. The term Micro-gasification refers to a small biomass gasifier that fits for cooking applications since it´s not bigger than that a standard pot fits on top of it.

2.4.2 Top-Lit UpDraft gasifier

The easiest TLUD gasifier is made from a simple tin can with an entry row of secondary air holes and another entry row of primary air holes are made to what becomes the combustion chamber (see figure 8). "Top-Lit UpDraft" refers to two key features for this kind of biomass gasifiers. The stove is lit at the top of the fuel bed which is loaded once with a batch of solid biomass. The primary air and the combustible gases flows upwards in comparison to the pyrolysis front which moves downwards through the bed of fuel. This facilitates the natural process where the hot gases and the air naturally rises because it´s lighter than the cold air that it is surrounded with. A natural draft of oxygen is created through the fuel bed satisfying the need of supply for the pyrolysis front. In the TLUD gasifier there are two things that moves: the first thing is the hot pyrolysis front which moves downwards through the fuel bed and converts the solid biomass to char. The other thing that moves is the wood gases that rises upwards from the pyrolysis front to the combustion zone. The solid biomass does not move besides from the part that it shrinks in volume when it dries and is pyrolysed. The supply of primary air controls the heat rate in the combustion chamber. It is possible to control the progress of pyrolysis front by regulating the available amount of primary air. The limited primary air that is available for the pyrolysis front to produce combustible gases only allows to create enough amount of heat to let the process continue which secures the conversion of char not to be combusted. The wood gases rises up to the combustion zone where the row of secondary air holes sits and additional air mixes with the gases and burns in a separate flame compared to the pyrolysis front (giz HERA - Poverty-oriented Basic Energy Service, 2011). This was conceptualized in the middle of the 80´s by Dr. Thomas B. Reed in USA but also separately by Paal Wendelbo in Norway in the beginning of the 90`s (giz HERA - Poverty-oriented Basic Energy Service, 2011).

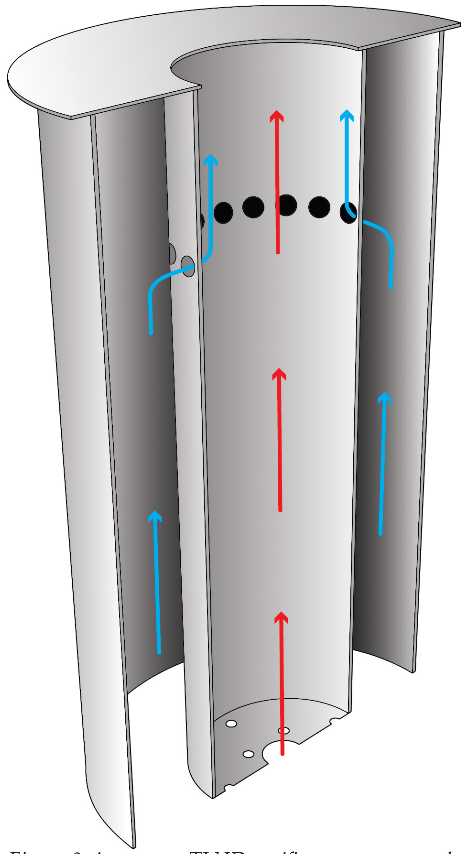


Figure 8. A common TLUD gasifier appearance and flows of primary, the red arrows, and secondary air, the blue arrows. The primary air inlet is at the bottom and the second air inlet is at the top in the pricture.

2.4.3 Influences by the design

The power output is controlled by the amount of wood gases that can be produced at a given time. The combustion rate mostly depends on the conversion of solid biomass to combustible gases by the pyrolysis front. This is controlled by four key characteristics. The first is the temperature within the combustion chamber. The higher the temperature is at the pyrolysis front the more gases are converted at the same time because of the higher quotient of lightweight particles in the air. Higher temperatures also makes the pyrolysis front travels more rapidly through the fuel bed and is thus able to create combustible gases faster. The second is the amount of primary air available directly affects the heat output at the pyrolysis front both by the speed the front is moving with and the intensity of conversion. This means that less air leads to less wood gases and less char is created from the solid biomass. The thirdly the diameter of the combustion chamber sets the size of the area for the pyrolysis front which can convert solid fuel to char and wood gases by moving through the fuel bed. A smaller diameter is equal to smaller pyrolysis front surface converting less biomass into gases at a given time frame compared to a bigger diameter. For the fourth is the fuel characteristics which determines the air supply through the fuel bed which make it possible for the pyrolysis front to occur. A high density fuel let less air through and burns slower than low density fuel. The firepower for gasifiers is also improved by increased heat in the combustion zone and protects it from cooling. One way to succeed with that is to insulate the combustion chamber or insulate the secondary air supply and preheat it before entering the combustion zone. By using an outer windbreak outside the chamber both the alternatives can be fulfilled. This protects radiation heat from leaving the combustion chamber by capturing it in the secondary air that rises along the sides between the windbreak and the chamber before it reaches the row of secondary air holes. The power output of gasifiers which can be regulated by the primary air supply need to take in account the amount of secondary air supply available which regulates the rate of wood gases that can be burn. Because only if there is enough oxygen available to combust the gases it will be transformed into power output otherwise the primary air will create wood gas that leaves the combustion zone unburned. The height of the combustion chamber is directly related to the burning time of the gasifier by defining the amount of solid fuel that fits into the chamber (Dr TULD P. S. Anderson, 2012).

The concentrate plate is another part of the stove that helps to create a turbulence of secondary air when it enters the chamber and as the name reveals concentrate it towards the middle which enhance the natural convection, through mixing of gas and oxygen. The plate affects the power output and directly the height of the flames. With a smaller inner diameter the height of the flames rises and the other way around. More specific The concentrate plate even gives the open flames protection aginst winds (giz HERA - Poverty-oriented Basic Energy Service, 2011). By the design it´s even possible to enhance the natural draft to raise the efficiency at the incineration and even decrease the dependency on weather conditions by using a fan to enforce the air through the stove which reveals the expression for it ”force convection” (giz HERA - Poverty-oriented Basic Energy Service, 2011).

Figure 9. Paul Wendbos three liter Peko Pe.

2.5 Current stoves

Currently, the Micro gasifier stove that exist on the market today and which has worked as a base for this project is the Peko Pe designed by Paal Wendelbo. Both the six liters variant for bulky fuel and the three liters variant for dense fuel has been used as an inspiration to get the understanding and the knowledge of the combustion process. But also the price of the stove on the market has been an inspiration trigger for the development process. The Peko Pe consist of 14 different parts and 14 screws which are needed to be able to assemble it. Plus one damper if the user wants to regulate the primary air supply during usage. For the stove´s capacity to combust solid biomass with clean smoke as result it only needs 8 parts and 8 screws. The other pieces are to facilitate a safe management of the stove. The design of the stove is simple but functional and more or less consists of bended and rolled metal sheets joined together. A more detailed description of the Peko Pe is that it has one inner cylinder with a bottom function as the combustion chamber. One outer cylinder as a windbreak and four legs that has the position of both holding the two cylinders in place and works as an distance between them. Besides of these parts it also consists of two handles and one concentration plate which also serves as a pot stand with three supports mounted on top (V. W. Cappelen, 2012).

There is a variety of different micro gasifiers on the market except from the Peko Pe which also has a broad price range. Some of the other stoves are listed below (P. Löfberg, and M. Olsson, 2012) (sep 2012).

Current stoves-Existing stoves on the market		
Brand	**Price (USD)**	**Draft**
Peko Pe	19	Natural draft
Philips woodstove	58 - 84	Fan assisted
Lucia	45 - 64	Natural draft
Champion	34	Natural draft
Oorja	15 - 35	Fan assisted
Sampada	30	Natural draft
Ezy stove	10	Fan assisted
Woodgas camp-stove	55 - 75	Fan assisted

Table 1. Showing some brands of existing stoves and their price range.

Current stoves-Peko Pe		
Dimensions (mm)	**3 Liter**	**6 Liter**
Inner diameter	160	190
Inner height	150	220
Outer diameter	195	230
Outer height	170	240

Table 2. Showing the measurements of the two variants of the Peko Pe.

Figure 10. Philips woodstove.

3. Project Process

The project execution has to follow an iterative process from the beginning to the end. This process has also mainly been used for the report outline. Easily it can be explained that the process started with an early design track which was a concept created to gather and use the ideas from the start-up session at Tre D Mekaniska. This was followed by the combustion part where basic information regarding the combustion process was collected through performance tests. New knowledge was also collected through interviews and literature studies. After the combustion part followed an idea generation phase which applied the knowledge into new ideas. The ideas where tested during evaluation which included new combustion tests with simple models, consultation with expert within different areas and statement from the company (Tre D Mekaniska). New information where searched to expand the knowledge level and created an increasingly detailed level of understanding. Together with the result from the evaluation phase this was compiled and used as a basis for a new idea generation.

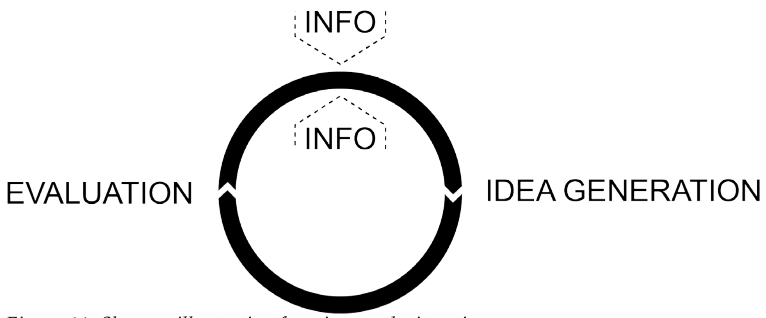


Figure 11. Shows a illustration focusing on the iterative process.

4. Combustion Part 1

During an interview with Paul Andersson, a expert and developer of micro-gasification stoves, (see page 80) he advocated the need of building models for testing and establish an own opinion about the design. Thus, models were build after his guidelines since they also gives a greater and improved comprehension regarding the combustion process. The test method is based on an operation where the result is determined after the products, services or processes one or more characteristics. The test is performed after a predefined procedure where the result is either qualitative, as right or wrong, or quantitative, as an measured value. A thorough research on combustion was performed continuously during the entire process. The research was done by physical combustion tests divided into three occasions: combustion 1, 2 and 3 and altogether seventeen tests were made. The focus of them was on the burning time and how it´s affected by the available amount of air. But other things which also could affect the combustion process were noted as weather conditions and how long time the different steps took. With the research the point is also to try the impact of the ratio between the primary air supply and the secondary air supply, where the hypothesis says it should be about 1/6 of the total air supply for primary air for good combustion (C. Roth, 2012).

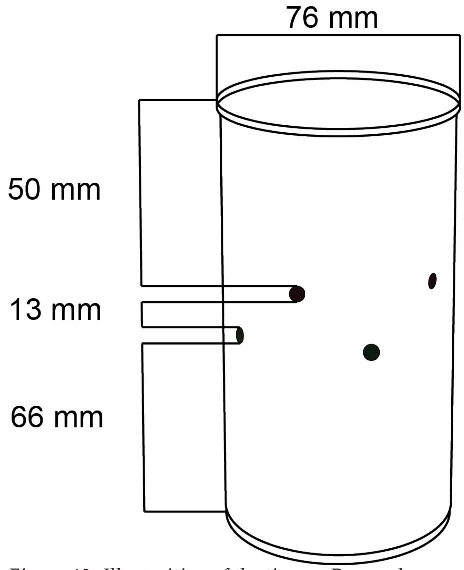


Figure 12. Illustraition of the tin can Pre-made soup with totaly 10 secondary air holes.

The tests were performed with different prototypes from simple single tin cans to proper manufactured concept ideas. In all the tests the fuel for the combustion was eight millimeters wood pellets bought and produced in Sweden. The procedure for the test were the same for all concepts tested which included the steps, ignition, burning time and extinguishing. To ignite the stove, first the pellets were placed in the combustion chamber and soaked with lightning fluid then paper was placed on top, small sticks afterwards and finally it was ignited from the top. When the fire has started no interference is needed for the process to continue. The step "burning time" has started and the process then continues until the flames are extinguished and smoke starts to emit. In the last step "extinguish" either the combustion process stops and biochar can be emptied or if there is a rich amount of oxygen available to access the fuel bed the process can proceed converting char into ash. In most cases the process is forced to stop during the last step of the test since this step is not of interest or relevant because in the long run the stove should produce biochar that can be used on arable land. For the first 5 tests the same kind of tin can had been used which is a regular tin can, pre-made soup. The can has a diameter of 76 mm and a height of 139 mm. The rest of the design has been done by guidelines from Paul Andersson. There is 50 mm of free space from the top of the tin can. Then there are two rows of 5 X 5 mm holes evenly distributed along the same row and 13 mm space between the two rows. The rest of the tin can´s height is for fuel storage and is therefore free space. There are two versions of the tin can. One where the bottom does not exist but only as a grid to support the fuel. The other one has four 5 mm holes in the bottom

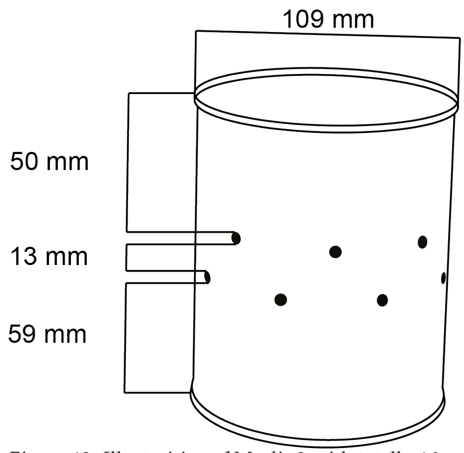


Figure 13. Illustraition of Mealie 2 with totally 16 secondary air holes.

but can easily be change into one with fewer holes through a separate plate with a predefined hole pattern which can be put beneath the regular tin can. For test 6-9 and 11 a bigger tin can was used called Mealie 1. This has a diameter of 109 mm and a height of 132 mm and has the same design as the regular one with the exception that the bottom only has three 5 mm holes evenly distributed on the surface. The test number 10 was performed also with a bigger tin can, Mealie 2, but compared to the earlier ones this has almost 50 percent as much secondary air input (see figure 12) evenly distributed in two lines with 8 X 5 mm holes as the one before with 13 mm space between the two lines. In all tests some form of windbreak was used together with a grid as a support for the stove to maximize air flow and to protect the combustion process. During tests one to seven a curved sheet was used as an windbreak which does not protected the whole stove only about 60 degrees of it. In the test eight, nine, ten and eleven a cylindric windbreak was used similar to the outer cylinder on Peko Pe. The same amount of fuel which were about 110 gram each time was used through all tests except for the test with Peko Pe where the double amount was used.

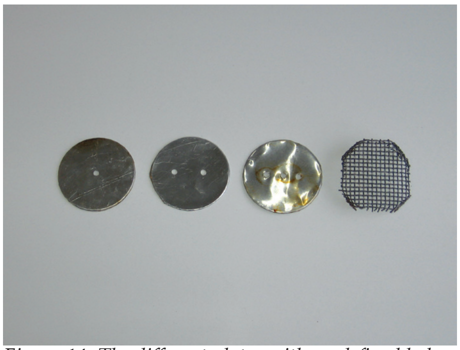


Figure 14. The different plates with predefined hole pattern together with the grid. Starting with 1/10 of the total air supply for primaru air, next 1/5, second 3/10 and last 10/10.

4.1 Tests 1-7

The first five tests were done exclusively to see how different amounts of available air influence the performance of the combustion process. This was done by changing the primary air intake from a ratio of 1/10 of the total air supply to almost 10/10 between primary air intake and secondary air intake (see figure 14). The result in burning time varied from 55 min to about 15 min where the test with ratio one tenth was really hard to ignite due to both the limited air supply and the weather conditions. Two other observation from the tests were that the burning with open flames was very hard to reignite if the flames had been extinct. The other observation regarding the limited amount of available air was that too little air makes the flames pass out before all the solid fuel is converted into char. The ratio of 2/10 was maybe even harder to ignite but it was only because of the wind conditions together with the restricted primary air supply which influences the flames and how they burn. Under such conditions they burn calmly and are small which lead to that the flames passed out a couple of times during the test time of 45 min burning. Test three with a ratio of 3/10 gave the best result of combustion among the first tests with big and steady flames. But it had the second shortest noted burning time, 40 min. One observation from the test was that during the whole time small amounts of visible smoke emissions were emitted. Due to the calm wind conditions when test four was performed the fuel burned smoothly without any complications for 40 min. The ratio for test four was 4/10. During test five with a ratio of almost 10/10 the burning time reached about 15 min in calm weather. After the burning with open flames the process continued with converting the char into ash resulting in an even higher heat output than with the burning flames. No smoke was emitted when the combustion of char took place. The two tests six and seven focus more on scaling of models to see what the


Figure 15. Visual resualt from the tests 4,5,3 and 6.

outcome turns out to be if the size of the combustion chamber changes from about 79 mm in diameter to 107 mm. From the tests 1-5 which received the best combustion results considering the heat output compare to the duration one test was chosen and scaled up which resulted in that test three with a ratio 3/10 was the selected one. Something that immediately was changed and observed during test six was the total burning time which dropped to 25 min and 30 min for respective tests when the size was increased. Another observation, made during test six, was that the combustion process was calmer than during test three. The burning time in test seven lasted for 30 min before the flames extinct and it´s was quite hard to ignite the prototype with a primary air ratio of 3/10. The various weather conditions in the seven tests didn´t affect the result in the end only affected the combustion during the execution.

Test result-Time duration	
	Total Burning time (min)
Test 1	55
Test 2	45
Test 3	40
Test 4	40
Test 5	15
Test 6	25
Test 7	30

Table 3. Showing the total burning time for the different test.

4.2 Test Peko Pe

One test was performed on the stove currently on the market, Peko Pe. This test has worked as a base for this project to have a reference object towards the other test results. But to observe the result of the Peko Pe test also has value on its own. The variant which was tested in this test was the six liters stove and the result from the burning could be summarized as a very good combustion. But the burning time was only 15 minutes and the only thing that remained was ash, all the char had been converted. The remaining ash depended at the combustion process couldn´t be forced to stop.

5. Concept Development

5.1 Analysis

Based on the result from the combustion part a thorough idea generation was conducted as an new iteration to broaden the range of ideas and to create innovative solutions. Before that could take place the project problem needed to be more deeply explored and defined. The current stove, Peko Pe, was analyzed and the different steps of the usage. This was performed by benchmarking through inserting the problem into a context where all the steps from manufacturing to end of life, transportation, assembly and usage were listed. But even all the small events within the steps were lined up. To create an even more thorough review a Hierarchical Task Analysis (HTA) was performed for one of these steps which is of high interest for the project.

HTA is a useful method that systematically structures a task into it´s subtask in the form of functions and operations. The operations are in the next step divided into goals and actions which gives the evaluator a more detailed view of how tasks are performed or should be performed and in which order. The method results in task maps that describe connections between different sub-tasks. HTA is useful in order to predict difficulties, performance, risks etc (L.-O. Bligård and A.-L. Osvalder, 2007).

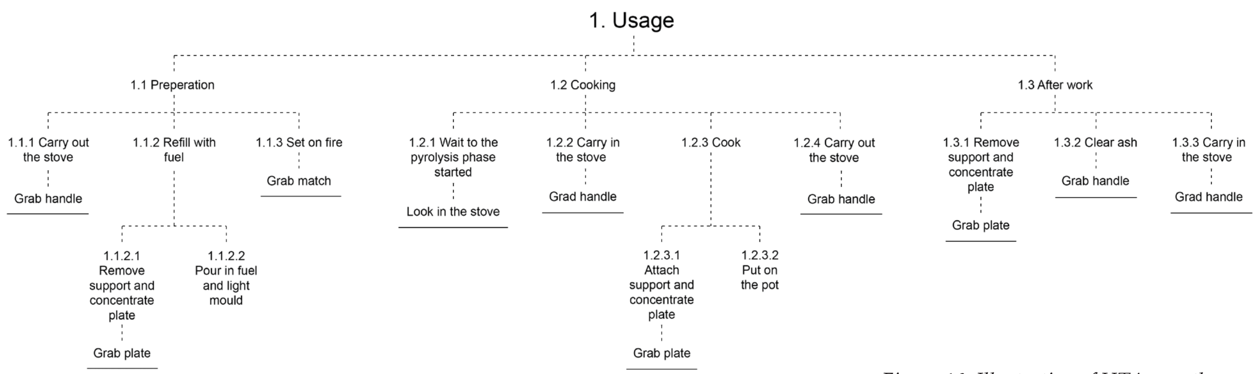


Figure 16. Illustration of HTA over the usage phase.

The usage of the stove in the households was the step which was chosen for the HTA analysis and the usage was divided into preparation, cooking and after work. After that preparation was divided into carry out, refill with fuel and ignite. In the same way cooking subsets, wait to the pyrolysis phase started, carries in, cook and carry out. The last event, after work, has the sub events remove support and concentrate plate, clear ash and carry in the stove. Regarding the HTA a lot of the events including carrying the stove when the it´s burning but also when it´s empty sets high demands on operation usability. The same thing can be observed with the concentration plate with the exception that the plate is not as heavy as the stove itself but can instead be very hot without any clear way to grab and handle it. From HTA the analysis proceeds with Enhanced Cognitive Walkthrough (ECW) together with Predictive Use Error Analysis (PUEA) of all the steps and events to try to catch problem and difficulties with the current stove and the handling of it.

ECW and PUEA make up a powerful combination of methods to evaluate an already developed product or system from it´s usability aspect. The methods give a good overview of what errors can occur within the system/product and what causes it but also how serious they are in relation to each other. The easiest way to use it is together with an HTA where the questions are applied on every step of the HTA both function and operation. ECW and PUEA are an active search method which puts the practitioner mentally in professional position (L.-O. Bligård and A.-L. Osvalder, 2007).

The first conclusion drawn from the method is that the current stove has a low technical level with few advanced functions and parts. This leads to few errors. The majority of the handling errors which are made in the households with the stove during cooking routine has low consequence impact and are easy to detect due to such things as massive smoke emissions, low boiling efficiency or difficulties to ignite. Even if the errors are of a more serious character they are easy to detect for the same reasons as the sentence before. The reasons for most of the errors are caused by actions and occurs while operating the stove in form of slips. Where the person had a good plan how to execute the combustion and cooking but fails in action due to lack of attention during execution. Actions are over represented as sort of errors and even if the most actions lead to low consequences it´s also the one type which causes the most permanent impairment or damage to body structure. Slips as error cause often leads to low consequences compared with the cause, violations, which if it occurs more or less always leads to serious consequences. The reason for this is that violations often are related to the dispersion of safety issues during usage. But often violation is easy to detect. In the same way slips are most easy to detect.

5.2 Requirement list

Having all information from the ECW and PUEA plus the knowledge from the theory a requirements list was created.

A requirements list is a list where all the requirements for the project that are needed to be fulfilled for the solution are visually represented. In the requirement list guidelines and wishes can also be included. All requirements which are listed need to be measurable to make it possible to verify if they are satisfied in the end and/or during evaluation. The task is often performed in the beginning of a project to always have something to use to verify that the project is aiming in the right direction and doesn`t fall out of track. A requirements list can either list the requirements in no specific order or the requirements can be weighted against each other and listed in relative order. This tool is useful through the whole process in the beginning to specify the terms for the solution and to keep track of the process, in the idea generation phase to come up with new ideas and in the end for evaluation (K. Ulrich, and S. Eppinger, 2012).

In the list for the project even the demands from the company in the form of sustainable aspects are included and even in some cases demands of manufacturing. To rank the requirements in order from the most important need to fulfill to the less important one, the requirements were weighted against each other. The five most important requirements were; reduce smoke emissions during use, reduce fuel consumption, reduce from burn injury, no toxic materials and the stove shall manage temperatures from 600°C to 900°C. The requirements in the list are presented from the top down with the most important first and the least important at the bottom of the list.

Requriments list	
No	**Description**
1	Reduce smoke emissions during use.
2	Reduce fuel consumption.
3	Reduce burn injuries.
4	No toxic materials.
5	The stove shall manages temperature from 600° to 900°.
6	No material hybrids.
7	All the parts shall be able to disassembly into the separated materials that it´s consist of.
8	The stove shall produce biochar.
9	Handle pellets size from 6 mm.
10	Be able to control the heat output.
11	Be able to control the primary air supply.
12	Be able to be produced without any advanced tools or machines.
13	Possible to repair without any advanced tools.
14	Support pot sizes 5-7 L in thin aluminum.
15	The fire shall last at least 2h with one batch of pellets.
16	The lifespan of the stove is at least 5 year of daily usage.
17	Easy to refill and empty the stove from char and fuel.
18	The size of the fuel container shall at maximum be 5-6 inch in diameter, preferred is 3-4 inch.
19	The stove should be able to handle both when it´s hot or cold.
20	Cost 30$ at most.
21	Prevent smoke emissions from extinct fire.
22	The stove shall be able to contain 3-4 L fuel.
23	Prevent smoke emissions from ignition.
24	Manage to be transported in flat packed.

Table 4. Showing all the requirements in the requirement list.

5.3 Idea generation

To start up and to better facilitate the idea generation an inspiration board was created.

The method has the advantages of facilitating the communication between persons and departments within the product development process. Inspiration boards are a visual method used for creating inspiration, to gather images that can inspire and display them in a collage. Often the Inspiration board is made based on a topic that it wants to express or affect. There are different kinds of boards like image boards, mood boards and expression boards, where their names clarify what they want to affect. An inspiration board can consist of everything from images, material samples, texts to colors to catch the essence of the topic. The method is mainly used in the beginning of the process during the idea generation phase or concept generation phase but can also be used as market analysis method to collect and express a company´s core value. Another important role that the inspiration board is used for is to represent design ideas and design approaches (K. Österlin, 2003).

The inspiration board for this project consists of existing solutions of different micro gasifications and camp stoves which were gathered together in a collage to inspire with different technical detailed solutions. Where Ezy stove from Ergonomi Design (ezystove. 2013) among others was represented is a stove aimed for firewood burning and a more efficient combustion process. The Ezy stove use the same idea base as this project with the idea to manufacture the stove in one country and transport it to another country where it is going to be used and assembled on site of local workmanship. The concept of letting the carrying construction be made of a cheaper material which will never come in contact with the open flames and the center of the heat has been an inspiration for the idea generation. But also the use of an independent carrying construction for the combustion chamber instead of using the chamber itself to support all the weight. This generated many new ideas on how to designing the stove (see figure 19).

To enhance the idea flow and the second point of application for the idea generation was to create a morphological matrix.

Morphological matrix is a systematic idea creation method made to come up with new ideas through connecting solutions of different part for a given problem. The solutions of the different parts are visually presented as pictures in a matrix and categorized in groups by which problem they solve. Then the only thing remaining is to draw lines between the pictures and link them together for different comprehensive solutions. With this method new concepts are generated from already existing solutions or shapes. It´s also good for collecting all the ideas in one place which facilitates the remembrance and to receive an overview (K. Österlin, 2003).

Morphological Matrix								
Fuel camber cross-section	Square	Round	triangle	Hexagon	Octagon	Rectangle		
Fuel camber 3D shape	Sphere	Cube	Cylinder	Cone	Rectangular	Pyramid	Tetrahedron	Octahedron
Support	Integrated	Non-integrated						
Numbers of support	Three	Four	More					
Handles	Integrated	Non-integrated						
Number of handles	One	Two	More					
Material of handle	Wood	Metal						
Primary air intake	Non-adjustable	Rotation round centrum	Rotation round side	Slide horizontal	Slide up/ down	Thread	Joint	
Size	152 mm	127 mm	102 mm	76 mm	Adjustable			
Usage	One	More						
Inner/ Outer cylinder	Together	Not together						

Table 5. Showing how the different cells with the sub solutions are linked together into new ideas with Morphological matrix.

All sub solutions, shapes, materials, sizes and usage etc were collected and later on linked together to create new different compositions. The ideas are represented by a line. The method resulted in a large amount of varying ideas.

A new images collection was performed to get a new view of the problem and to use as backcasting, (is a method used to reach a determined goal by clarify the actions) to see were I will achieve in the end and then determine the actions to reach that goal. As help the same expression as a grill radiates was represented in the collage. The idea was to catch the expression of a stylish and well shaped product and use it for the stove which today has no particular appealing expression. Because the stove is quite similar to how a grill works and look like operatively with more or less the only exception is that a grill is bigger and the stove will have a pot placed on top for cooking. With help of the new angle of incidence inspiring ideas were generated which were sketched by simple means (see figure 20). One specific grill stood out among the others and has inspired the project. The brand Eva solo has launched quantity of different models where all the parts are placed on top of each other and are either hanging on the outer part or placed in each other from the bottom (eva solo. 2013).

In the interview with Paul Anderson (see page 80) he said that he believed and saw the potential to produce a smaller stove with an inner diameter of only three to four inches for the fuel chamber. This he explained by the argument that it expands the field of use from not only the developing countries and the third world but also to the developed countries where the big market are the outdoor usages. This has resulted in new ideas of stoves which should be able to use more than one stove at the time and even connect them together (see figure 18). The ideas does not has to taking into account that it has to support the weight of a standard pot due to it´s a separate product and should be used together with a pot support.

At last an own separate image search using synonym word list to gather ideas on how to shape the primary air inlet was implemented (see figure 21). It was used as guide for the appearance of the air intake and was later on used during further development to determine of the same. The words which were applied for the idea generation was damper, valve, air intake, inlet, indraught, air supply, primary air and flap. Ideas to the inlet was also inspired by different existing items with smart and simple solutions like a ballpoint pen. How it works to get the tip out by clicking or twist.

To manifest the new ideas which has been generated and be to able to process them sketching was used. Sketches are an important tool for a designer to have in his or her tool bench. With sketches ideas are visually expressed for communication between different departments, persons and groups within the product development process. They are also used to create and come up with new ideas in the first place. It can also be used for documentation. Sketching can be performed on different levels from idea sketches which are quick and with less precision to renderings sketches which are more photo realistic (E.Y.-L. Do, 2005).

5.4 Concepts

All the new ideas which came up and been created during the idea generation were gathered together and sorted in different categories after the manner they were constructed. More or less all the ideas were kept and sorted into concepts where one idea in each group were picked out to represent the concept which has been the most promising and elaborated. The gathering ended in four overall concept of stove and one focused only on the primary inlet. Common for all the concepts presented below are that not too much detailed solutions has taken into account.

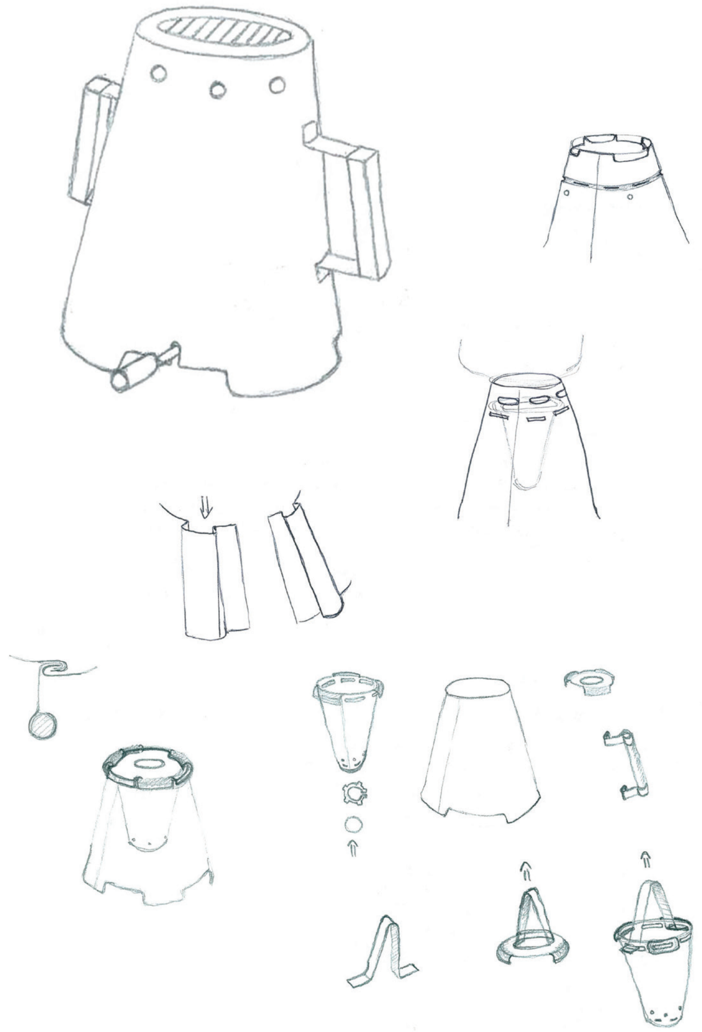


Figure 17. A image of the cone concept.

5.4.1 Cone

The concept was based on the idea of using two cones turned towards each other, one positioned in the other. This gives both a stable impression and implementation of the stove. The basic idea was that the two cones should consist of metal sheet which could be taken apart into a flat package to facilitate transportation. The disassembly and assembly of the stove is not supported by extra special parts like screws or nuts but only by the shape itself and the tension in the material which will keep the cones in position. The shape together with the position of the two cones gives a natural suspension of the inner cone by the attachment of a flange at the inner cone base which makes it little bigger than the outer cylinder top. This also facilitates the operation of the stove during refilling and emptying of fuel, when it´s possible to only lift the fuel chamber. The concept consists of one wood handle which is held in place by the outer cone joint which is assembled in the same time as the outer cone is since the handle is placed in the joint when the sheet is forces together and fixed. The pot support is made out of a flat sheet which is folded to produce the actual support. To decrease the numbers of parts of the stove the concentrate plate is integrated in the pot support.

Pros	Cons
+ The concept is stable due to the shape. + The concept gives some protection against burns. + It´s possible to take the cone apart and put it together.	- Since the shape needs to be rolled the need for a new machine makes it expensive. - The cone increase the material consumption which increase the costs.

Table 13. Pros and cons reagrding the cone concept.

5.4.2 Small

The concept is not so much its own concept more than the idea of using the shape of a hexagon to connect several stoves together without creating any free space between the stoves, a homogeneously pattern. Where the concept does not has any unnecessary parts which sticks out from the outer cylinder. Focus with the concept was to easily operate the stove alone or together with others. When there is more than one stove stand next to each other the handles point from one another to facilitate the ability to reach a separate stove even if it stands under a support with a pot. Almost all the other concept solutions can be used as the small concept with some modifications as mentioned above. With a carrying construction of the chamber its own or by a separate construction like the one with rods.

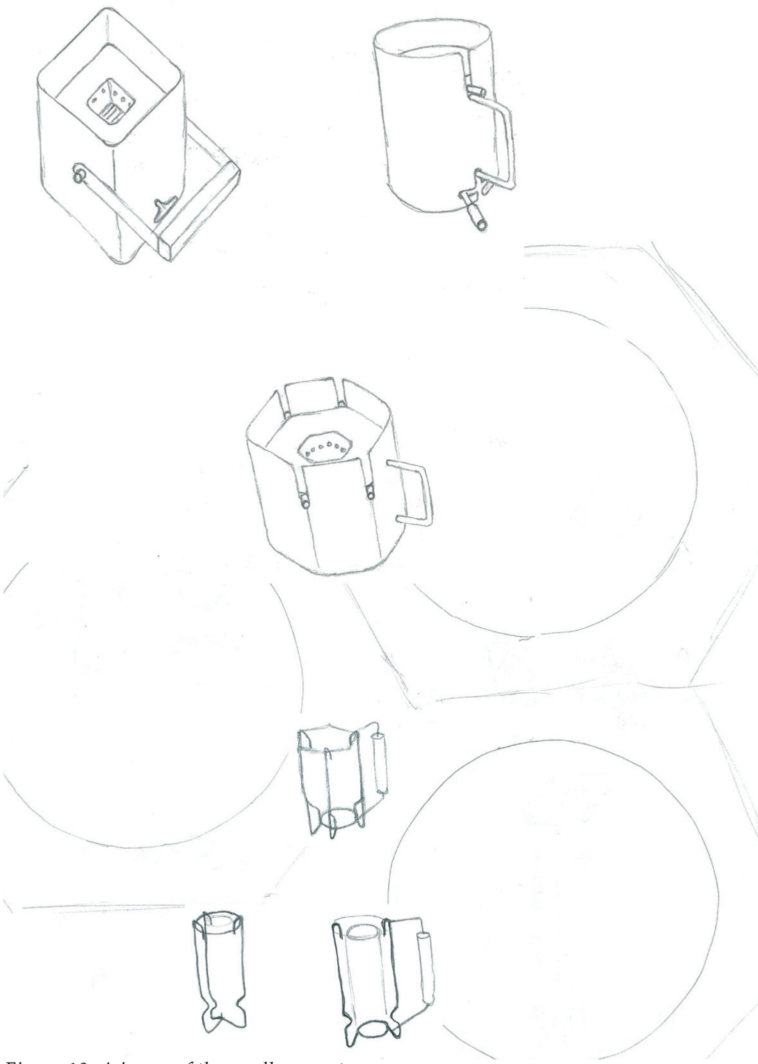


Figure 18. A image of the small concept.

Pros		Cons	
+	Easy to adapt for different situations.	-	The concept will increase the need for material consumption.
+	The stove is easy to operate to more people.	-	Need a separate pot stand.
+	The shape provides no unnecessary free space when connect together.	-	Does not protect against burns by it´s own.

Table 6. Pros and cons regarding the small concept.

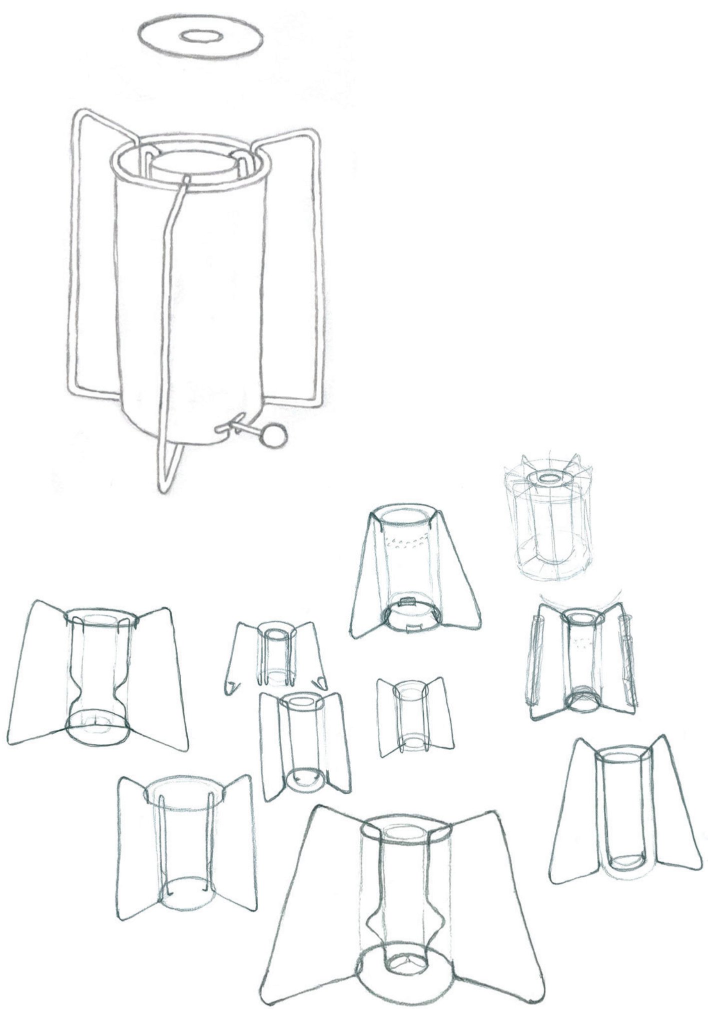


Figure 19. A image of the rode concept.

5.4.3 Rods

The concept is inspired by Ergonomi design Ezy stove where the main idea were to build a firm construction in itself out of rods without the combustions chamber in place. In this manner the combustion chamber be custom made to minimize the material consumption and not take into account that it should be able to support the weight of a pot or cooking. With the idea of make a construction out of rods which will have no contact with the heat source or the open flames make it possible to use other materials than stainless steel emphases the use of more local produced materials and cheaper materials. One focus has also be to make the stove easy to assemble and disassemble and replace parts. This is solved by the concept through that it does not exists screws or other joining parts. With the concept the big concern about the ability of operating the stove has facilitated by the three legs which also are handles. The support for the pot in the concept is also the same part of the construction as the legs and handles which except from works as support in the same time be a burn protection because its angled and follows the pot and prevents it from tilting. The number of legs has take into account the most stable formation and become inspired by camping stoves with only three legs and three support arms for the pot.

Pros	Cons
+ The construction provides with good support.	- Need broader professional skills.
+ The concept enhance the possibility to reduce the amount of expensive material.	- Gives little protection against burns.
+ Assembling without screws and nuts.	
+ The support also provides handles.	

Table 7. Pros and cons regarding the rods concept

5.4.4 Grill

The concept has been influenced by todays grills which has a more worked through appearance and expression. A grill works almost in the same manners as the stove which make it easy to implement. With the inspiring of a design as the Eva Solo or others it´s easy to produce an integrated burn protection within the concept construction. The concept is conical with tapering towards the ground but the bottom area is not smaller than the biggest pot used on the stove. This creates a natural air gap between the burn protection and the pot together with slot along the sides which makes it possible to hang the inner cylinder and grill rack in place. A grill rack of standing unsymmetrical bars creating right distance between the open flames and the pot. The rack also provide with the concentration plate which is integrated aiming to minimize the different kinds of parts. The concept is intuitive to assemble due to the few parts and the smart way in which the different parts fit into each other by either stack them in each other or hanging them from the outer edge. Where the carrying construction can be both the combustions chamber or an independent construction of rods.

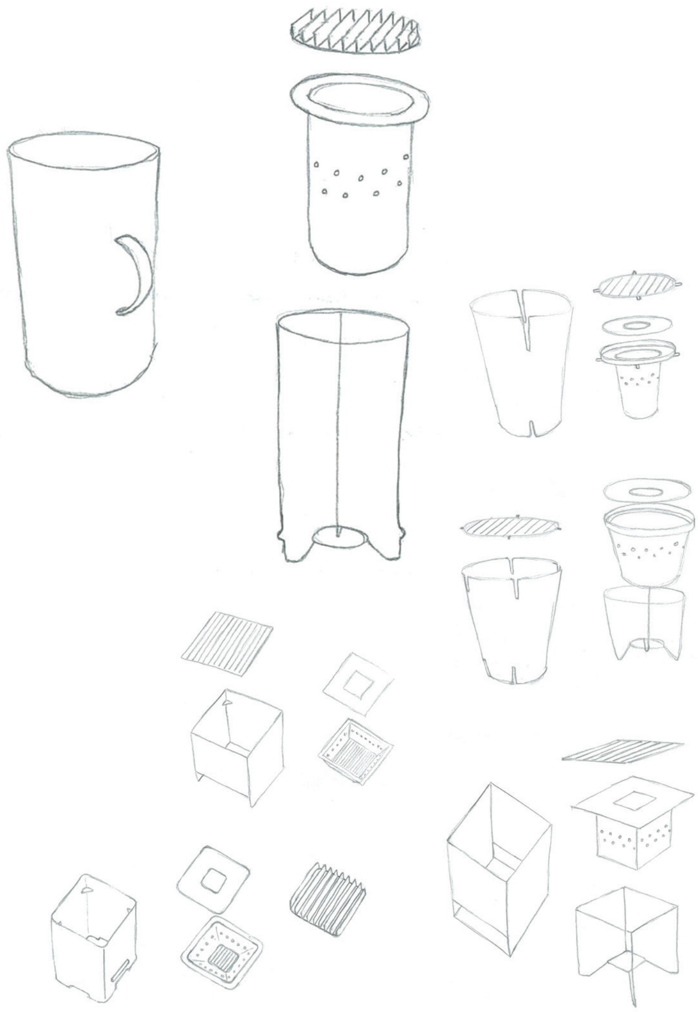


Figure 20. A image of the grill concept.

Pros		Cons	
+	The concept can provide burn protection.	-	The shape does not reduce the material concumption.
+	Easy to assemble.	-	With burn protection the stove limits the size of pot.
+	Good total solution.		
+	Integrated concentrate plate within the pot support.		
+	The burn protection also provide a wind break.		

Table 8. Pros and cons regarding the grill concept.

Figure 21. A image of the inlet concept.

5.4.5 Inlet

The concept specific on the inlet focus only at different solutions regarding primary air intake as how it should applied at the combustion chamber. Where ideas from common air dampers which exist on almost every grill to ideas mimicking a ballpoint pens twist or click are presented. There are also ideas where an external sliding parts is used to cover the air opening by sliding it up and down along the inner cylinder. Sliding it forth and back inspired by salt package or some other packages where the opening can be changed depending on how much of a specific product is wanted from entirely open, half open to closed. Ideas of using a hinge and a flap to control the air supply was presented.

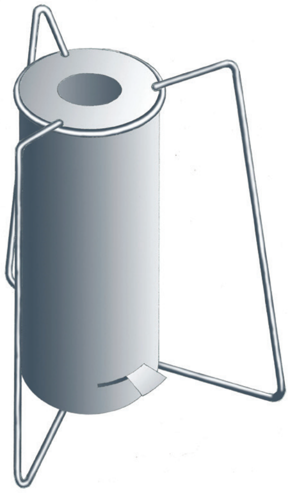


Figure 22. Shows the sketch of concept rods used for the presenation.

5.5 Presentation in Malmö

The Presentation for Vagga till Vagga in Malmö was conducted with the five concepts, cone, small, rods, grill and inlet, each represented on a separate A3 paper together with a digital presentation. For the presentation in Malmö concerns regarding the different concepts which had arisen throughout the development process were presented and discussed. In this the concepts were included but also concerns which had arisen from the experts consultation (see page 43). There was also a short video showing the result from one of the more successful combustion test (see page 28).

The meeting with Vagga till Vagga was held to inform them about the progress of process and to be able to show what has happened since start. But also to be informed of what their latest step has been in ways of getting closer to production and launch of the pellets and the stove. Another important role of the meeting was to determine one design track to continue with and develop further during the rest of the project duration. This concept needed to be decided with consults from Vagga till Vagga since they are the company and the ones who have decided to take this to production and promo it. The presentation was conducted in Vagga till Vaggas office in Malmö, southern Sweden, together with Per Löfberg, one of the owners of Vagga till Vagga. It was an open meeting were it was discussed which concept should aiming for in terms of pros and cons for each concept. In the end it could be agreed on one concept which was both innovation and promising. The concept that were agreed on was the Rods.

5.6 Presentation for Tre D Mekaniska 2

The idea that was pick out to be presented for Tre D Mekaniska were the concept Rods. This because it was the most different solution from the Peko Pe with potential to cover and try out the ideas behind the other concepts too, like rolling and bending etc. The concept were drawn and illustrated by both drawings and digital sketches to simplify the understanding of the concept to facilitate for the company during the decision making regarding if they could produce it. This was presented for the company through mail which were sent to them with all the drawings and sketches (see figure 22).

Their answer was that they were uncertain, first because they did not work with wire bending in generally and secondly they think that it was little to complicated the ways of how the outer cylinder was assembled. They were not truly satisfied with this solution either. But they added in the same time that it was not impossible to collaborate with another company to produce the wire bending if this concept idea turns out to be the most promising regarding to the others ones.

6. Combustion Part 2

6.1 Expert consultation

In the project three experts were contacted for consultation regarding their field of expertise within two different institutions. The experts were Niklas Vahlne, Henrik Thunman from energy and environment department, Mats Norell working at materials and manufacturing technology. The idea behind the consultation was to use them to raise their critical opinions, questioning the different concepts ability to perform in the end. They were the critical party who was used as basis for evaluate the concepts among themselves to be able to sort out and select a concept for further development together with the opinion from Vagga till Vagga.

The first person, Niklas Vahlne, who was consulted, worked with implementations of improved cook stoves around the world and investigated how it had worked out. How different stove programs had been accepted by the people in their country and how they were implemented from the beginning. The result from the consultation was that about every stove program that has tried to been implemented has failed in the first years. The big issues had been that stoves have not been able to perform in the same manner as they should. The stoves have broken, not satisfied the target group needs, the pre standard have not reached as high as it should or they have been free of charge. This is because the stoves has been developed in the developed countries without knowledge regarding the users habits, needs and not probably tested in the real conditions at the site but only in lab. It could even be that when the program were implemented the stoves themselves did not cost anything leading to that the people were careless around them and did not payed attention when using the stoves.

Henrik Thunman was the next person which were contacted at the department of gasification. From the conversations with Henrik he mentioned that the basis for good gasification is to get good mixing between air and fuel, it´s about to achieve and obtain an even air flow through the fuel bed during the whole combustion process. Important to know is that air always takes the easiest way which mean that it´s good to be aware of the pressure drop is located especially if it´s the same source of air to both the primary and the secondary air. With a limitation in the inflow it´s possible with the same source to receive all air as either primary or secondary air depending on were the limitation is. This is favorably to be controlled with a damper to adjust the process to the actually situation. Using wood pellets as solid fuel in the stove the right pressure drop is created with the porosity of the pellets therefore it is important to establish an even fuel bed. The ratio between primary air and secondary air for a common incinerator were the air can be regulated is one to one. In the incineration process 20 percent more air is added in combustion process than is needed for the incineration which means that about 60 percent of the air is primary and the rest is secondary. But for natural convention the ratio need to be higher than one to one. Regarding the concept with the cone the shape tends to conduct the flow along the walls were the resistance is lowest. This leads to that straight walls is more common used for combustion chambers made of solid materials. To avoid smoke emission during ignition and extinguishing it´s preferable to use a small amount of pellets to ignite and then add on exactly the right amount which all going to be incinerated during usage.

The corrosion expert Mats Norell were consulted concerning the choice of material, the impact of it and how the best way to design the combustion chamber base from the material. The result were that even with the use of stainless steel it´s matter of time before the stove will start to corrode due to lack of oxygen and the high temperature within the chamber. To preserve the chamber as far as possible it´s good if the open flames do not come in contact with the walls and the material. For the protection of the stove it is good if the walls are insulated with ceramic and even with a shielding gas inside the ceramic. The extinguished smoke and gas should only come in contact with the insides and not the open flames. A good role is to always have the thickest material closest to flames and thinner further out.

Figure 23. Visual result of the test 10, at the right, and test 11 at the left.

6.2 Test 8-11

Combustion part 2 represents by test 8, 9, 10 and 11 which was performed to try the theories in practice which had been said during the expert consultation to be able to document the outcome.

The test eight was conducted in breeze weather condition and the total burning time reached 30 minutes for the test. The result from the test was that the stove were easy to ignite and when it burned with open flames it lasted in 30 minutes without any complications before the flames extinct by itself. A observation when the stove was empty that there were unburned pellets left in the combustion chamber. Test nine´s burning time was recorded to about 30 minutes and the weather condition for this test was almost windless. During test nine a grid was used to build an air gap between the primary air intake and the fuel bed to provide a more even spread of air flow which also was used in test ten and test eleven. Compared with test eight the stove was little harder to ignite and it took about 5 minutes. During the burning time step the stove burned with no need of interfering in about 30 minutes. With the grid in the bottom the incineration result were better than for the test six, seven and eight. In test ten and eleven the concentrate plate from Peko Pe was used and the hole in the plate was equal to the diameter of the combustion chamber. The test ten was performed in calm weather and had a total burning time of about 30 min. This test was the easiest to ignite and after only three minutes were the stove burning by itself. The burning time proceed well with no complications but it really took off after about 16 minutes and lasted in about 10 more minutes. The combustion process slowed down to a much calmer burning in 3 min before the flames extinct totally. It was possible to grab the

Test result-Time duration	
	Total Burning time (min)
Test 8	30
Test 9	30
Test 10	30
Test 11	28

Table 9. Showing the total burning time for the different test.

outer cylinder during almost the whole test time except from the last 5 to 8 min when it got too hot. The result from this test could summarize into the best outcome of all the tests. The test eleven was executed in calm weather conditions with a total burning time of 28 minutes. When the test were performed it were easy to ignite the stove which took about 6 min before it got started. In the beginning the stove burned with calm flames but after about 17 min the incineration process accelerated which led to more and higher flames and this state was retained in about 8 min. For the last minutes before the stove extinct the flames were really few, small and the process was calm. During the whole test period the stove burned without any complications.

6.3 Requirement refinements

With new knowledge regarding incineration process from the latest combustion test, the expert consultation and whats has been decided during the meeting with the company in Malmö a new requirement list were put together to emphasize on the new discovered priority among the requirements. The requirement list has also some new requirements to simplify the implementation of the list during further development process. Other requirements has been removed due to that they are to hard to fulfill within the stated aim for the project.

Requriments list	
No	**Description**
1	Reduce smoke emissions during use.
2	Reduce fuel consumption.
3	Reduce burn injuries.
4	No toxic materials.
5	The stove shall manages temperature from 600° to 900°.
6	No material hybrids.
7	Cost 30$ at most.
8	The stove shall produce biochar.
9	Handle pellets size from 6 mm.
10	Be able to control the heat output.
11	Be able to control the primary air supply.
12	Be able to be produced without any advanced tools or machines.
13	Possible to repair without any advanced tools.
14	Support pots sizes with a diameter between 120 mm and 240 mm.
15	The stove shall be able to contain 3-4 L fuel.
16	The lifespan of the stove is at least 5 year of daily usage.
17	All the parts shall be able to disassembly into the separated materials that it´s consist of.
18	The stove should be able to handle both when it´s hot or cold.
19	Easy to refill and empty the stove from char and fuel.
20	The size of the fuel container shall at maximum be 5-6 inch in diameter.
21	The fire shall last at least 2h with one batch of pellets.
22	Manage to be transported in flat packed.

Table 10. Showing all the requirements in the requirement list.

7. Further Development

7.1 Concept development

After the meeting in Malmö and the decision to proceed with the concept Rods (see page 42) for further development a new idea generation was implemented to improve the feeling of being an intuitive and easy solution as the concept grill yielded. The focus has been on the rack and how to assembling the stove. Another decision was to use the result from the combustion tests for the design solution of the combustion chamber because it only need to provide with good incineration result. Furthermore a new iteration of the air inlet was also performed to enhance and make it fit the total solution as stove. The next idea generation was performed without using the earlier sketches as a based for the new ideas. Instead the idea creation was based on how to put the different parts together and in which directions they are supposed to be composed in. The idea generation was even created with regards on how well the outer and the inner cylinder are fixed. Some account has been taken for the Ezy stove design during the development of new ideas aiming to go at the opposite direction in which it´s possible to avoid come up with to similar solution. During the meeting with Per Löfberg, one of the owners of Vagga till Vagga, it came up an a idea regarding the air supply of letting the damper be loose and positioned from above in the combustion chamber. This idea worked as a starting point for further development both for the existing idea and for new ones. The generation phase ended in 11 new ideas of constructions on racks were developed and a couple of good solutions with variations for the air intake.

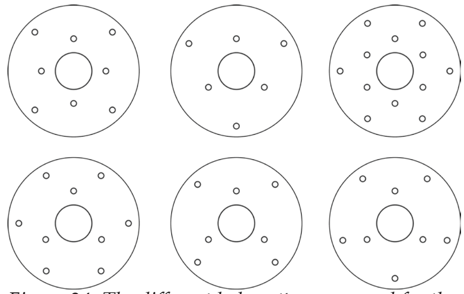
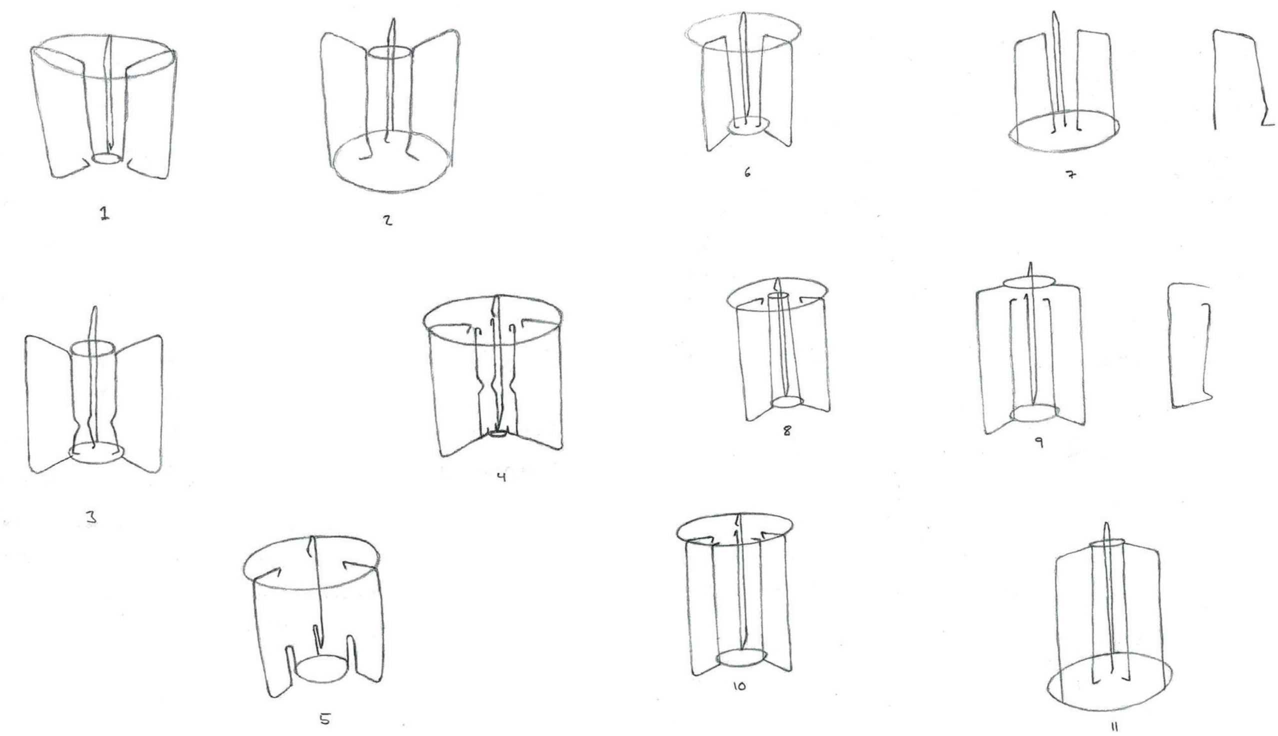


Figure 24. The different hole pattern proposal for the air intake.

Figure 25. All 11 ideas of the rack.



7.2 Validation

To be able to validate the different ideas against each other a framework was put together with the ideas of the rack in a row at the top and with the criterion in a column to the left.

The Pugh matrix is presented in words or pictures in a row and the criterion set which they shall be evaluated against are represented in a column. One idea or concept is picked as a reference object which all the others are compared with. The concepts are compared with the reference object on how well they fulfill the criteria and if the concept is better it´s get a plus sign otherwise its gets a minus sign, it can also receive a zero if they are in equally good. In the end the different scores are collected and the reference has the score zero. Hopefully one concept has a higher score and eliminates the other ones. All the concept or ideas can be used as a reference object but its advantageously to use the existing idea or concept as a reference. It is preferable not to use too many criterion in the chart and instead focus on the most important ones (K. Ulrich, and S. Eppinger, 2012).

In the project the framework consisted of all the 11 different construction ideas for the rack to the stove. One of the ideas was picked as a reference object which all the other ideas were compared with and assessed against. They were then evaluated against 13 criterion: functions, how many welds there are, numbers of radius, which directions the cylinders are thread from, if the cylinders are clamped, loose or suspended and how many support points there are in the construction. The reference idea was decided to be the most bold idea with the cleanest and the simplest form language, idea number seven. In the end the 11 ideas were scored by how well it managed to fulfill the criterion compared with the reference and the ones with the highest score passed. Five ideas passed because they were to similar to each other and it was hard to separate them by score (see table 11). The ideas that passed were number seven, three, six, nine and eleven. They were supplemented with comments regarding thoughtful issues and concerns for the final decision making. All the ideas were picked except from idea number nine because the suspension affected the combustion process. The suspension of idea number nine uses the secondary air inlet and reduces the amount of air that passes through. It also reduces the life span of the rack and increases the risk of burns due to the rack being in directly contact with the flames and conduct the heat better through the steel. The framework couldn’t use the requirements as the criterion. The criterion was rather based on the manufacturing and the assembly details of the rack since the requirements in the requirement list focused on the full concept and not on parts of it like the rack.

Validation framework-Constructions ideas for racks.											
Criteria	**Reference 7**	**Concept 1**	**Concept 2**	**Concept 3**	**Concept 4**	**Concept 5**	**Concept 6**	**Concept 8**	**Concept 9**	**Concept 10**	**Concept 11**
Numbers of radius	9	12 (-)	12 (-)	21 (-)	27 (-)	18 (-)	12 (-)	12 (-)	12 (-)	15 (-)	9
Numbers of Welds	3	6 (-)	6 (-)	6 (-)	9 (- -)	6 (-)	6 (-)	9 (- -)	6 (-)	6 (-)	6 (-)
Numbers of rings	1	2 (-)	2 (-)	2 (-)	2 (-)	2 (-)	2 (-)	3 (- -)	2 (-)	2 (-)	2 (-)
Inner cylinder is loose	No	Yes (-)	No	No	No	Yes (-)	No	Yes (-)	No	No	No
Inner cylinder is clamped	Yes	No (-)	Yes	Yes	Yes	No (-)	Yes	No (-)	No (-)	No (-)	Yes
Inner cylinder is suspended	No	No	No	No	No	No	No	Yes (+)	Yes (+)	Yes (+)	No
Inner cylinder is threaded from the bottom	No	No	No	No	No	No	No	No	Yes (+)	Yes (+)	Yes (+)
Inner cylinder is threaded from the top	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No
Outer cylinder is loose	No	No	No	No	Yes (-)	Yes (-)	No	Yes (-)	No	Yes (-)	No
Outer cylinder is clamped	Yes	Yes	No (-)	Yes	No (-)	No (-)	Yes	No (-)	Yes	No (-)	Yes
Outer cylinder is threaded from the bottom	Yes	Yes	Yes	Yes	No	No	Yes	No	No	No	Yes
Outer cylinder is threaded from the top	No	No	No	No	Yes (-)	Yes (-)	No	Yes (-)	Yes (-)	Yes (-)	No
Support points	Infinite	3 (+)	Infinite	3 (+)	3 (+)	3 (+)	3 (+)	3 (+)	3 (+)	3 (+)	Infinite
Total	0	−4	−4	−2	−6	−7	−2	−8	−2	−4	−1
Passes the first stage	Pass			Pass			Pass		Pass		Pass
Comments	Need something that guide the inner cylinder and fixes the outer cylinder.			Does not need anything. Is the top ring required for the stability?			Is the same as the reference. Is the top ring required for the stability?		Need to be change so no contact is required between the support and the combustion of smoke.		

Table 11. Showing the frame work which was use for validation of the further developed ideas together with the comments and the result.

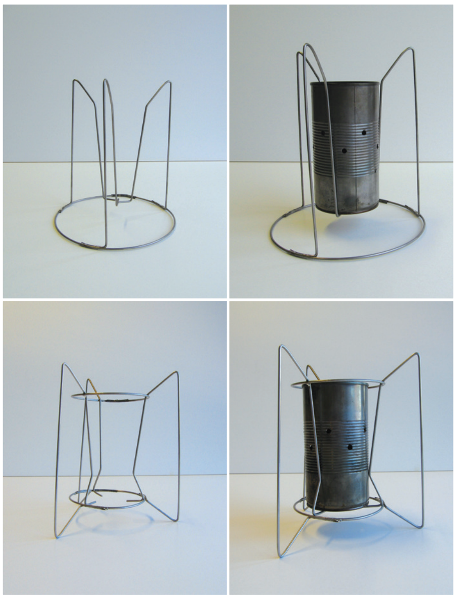


Figure 26. The two produced models of the rack, idea nr 7 the preference and nr 3.

7.3 Model of the support

To facilitate the choice of idea in the end and support validation, two scale models in 1:1.5 were built of two of the racks which fits the pre-made soup tin can.

Physical models were made to create a view of the proportions regarding an object between different details and parts or on the human body. A model can also be used to test and analyze a products functionality through a prototype. The ergonomics and anatomy are easiest to try out with a full scale model or a mockup. For presentations a physical model can be good to promote and visualize things such as texture, materials, shapes and size to solutions. There exist different kinds of models but most are either smaller scale models of things that normally are bigger in reality, like houses, or bigger scale models if they are smaller in reality(K. Österlin, 2003).

The purpose of the two models of the rack was to try to see the ideas in ways of how stable they are compared to each other depending on the criteria. But to test it together with the inner combustion chamber to see how well it´s fixed and how the combustion chamber will affect the rack. The ideas which were chosen to build were first the number seven, the reference object, and the second was number three. They were chosen to cover the most of the four picked ideas from the validation. One with three support points and one with infinite. But also because the four ideas were quite similar and building all were not necessary for the purpose of testing the stability. Both the ideas were built out of three millimeter bent welding wires. The result was with few modifications of the design as expected and worked well together with the tin can which gave more stability to the construction than was expected. The need for a upper ring to stabilize the rack was not necessary because of the two cylinders. The impression when using three millimeter wires was that the rack feel a little to flexible and it was not to comfortably to grab. But both of the two models worked fine with the idea of using the wires flexibility to fix the position of the cylinders and there was no sense that the tin can should come loose. With the help of the validation and the two models a final concept could be determined.

8. Final Result

Figure 27. The stove, Hestia - the goddess of the hearth.

8.1 Design

The result is Hestia, the Greek goddess of the hearth and the fire in the hearth. She presided over the cooking of meals, the happiness of the home and the community´s harmony.

Hestia is a stove designed for use of a single cooking pot for meals. It is built on the principle of natural convection to support the incineration with fresh air to push the process forward. With the stove it´s also possible to regulate the primary air supply to receive better control of the process and to get a better adaptation.

Hestia consist mainly of two different parts, first the combustion chamber and it´s outer casing and secondly the rack which holds the chamber in position. The chamber itself has a cylindrical shape and consists of five pieces, wall, bottom, damper, grid and concentrate plate. The size of the chamber is smaller in diameter than the existing stove which has been working as a basis in this project. This has been a balance between the heat output, i.e. what it can achieve and the duration for the stove on one batch of pellets. The chamber can still accommodate a total amount of three liters of wood pellets which has been a crucial point to avoid the need of refilling the stove to frequently (see page 45). In total the chamber is 250 mm high and has a diameter of 125 mm. Starting from the top the combustion chamber has a free distance of 75 mm before the two rows of secondary air intake. This in order to build a good distance between the flames and the cooking pot. The two rows sit with a 30 mm distance and consists of 8 X 5 mm holes to provide a correct mixture of air and smoke for the combustion process. After the two rows there is a distance of 135 mm with extra free space for the fuel storage (see figure 28). The outer casing is 16 mm wider on both sides of the chamber to provide a gap for the secondary air to travel in and get preheated at the same time as it protects against wind (see figure 30). In the bottom there is 8 holes for the primary air supply. These are evenly distributed with each the size of 5 mm and a center hole of 32 mm for the slider on the damper. The damper is slightly smaller than the bottom with a diameter of 115 mm to fit in the chamber without getting wedged (see figure 29). It has the same hole pattern as the bottom except for the one in the center where the slider, which is a piece of bent metal sheet with a shape as a U, is attached. The shape makes it possible to regulate the primary air supply by means of a rod. Next part is the grid which, just as the damper, is a little bit smaller than the bottom, with a diameter on 120 millimeters, to avoid getting wedged and to be able to fit in the combustion chamber. The size of the hole in the grid is determined to 3 mm which allows the air to flow through, but prevents solid fuel or pieces of solid fuel from dropping down. The grid has been added with a rim to lift the fuel bed from the bottom to create an air gap between the fuel bed and the primary air inlet which facilitates an even spread of air flow. The last part in the combustion chamber is the concentrate plate which focuses the heat from the stove to the cooking pot and creates a better turbulence in the flames resulting in a more efficient incineration (see figure 31). It also influences the size of the flames and to some extent how wind-

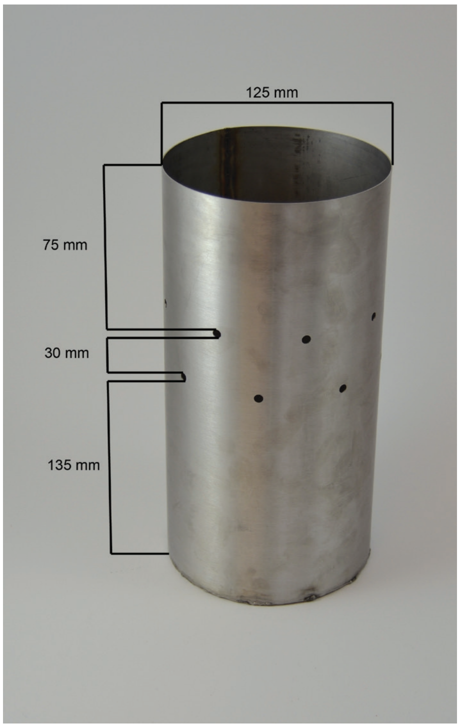


Figure 28. Combustion chamber.

Figure 30. The inner casing and the outer casing.

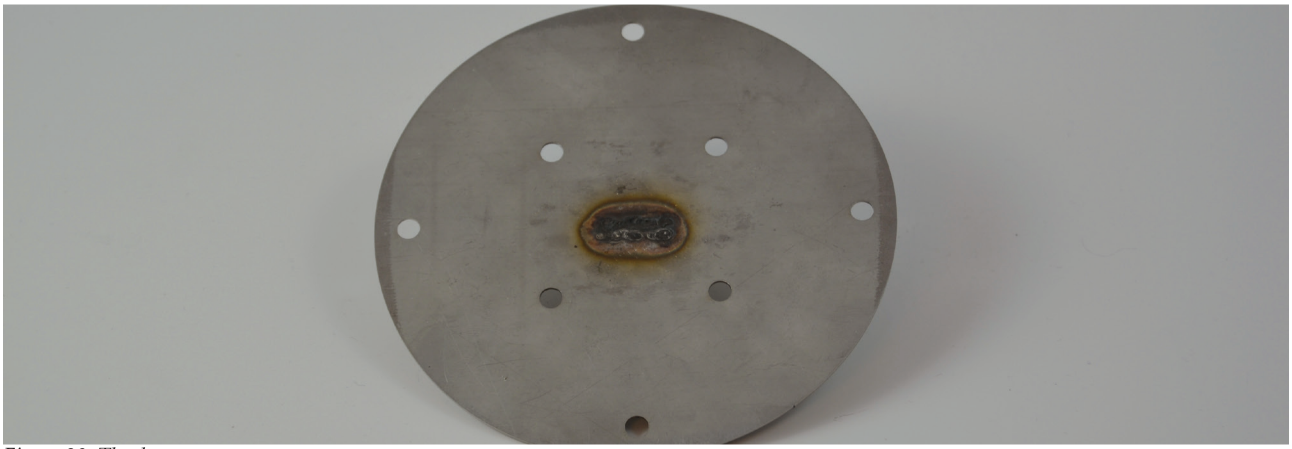


Figure 29. The damper.

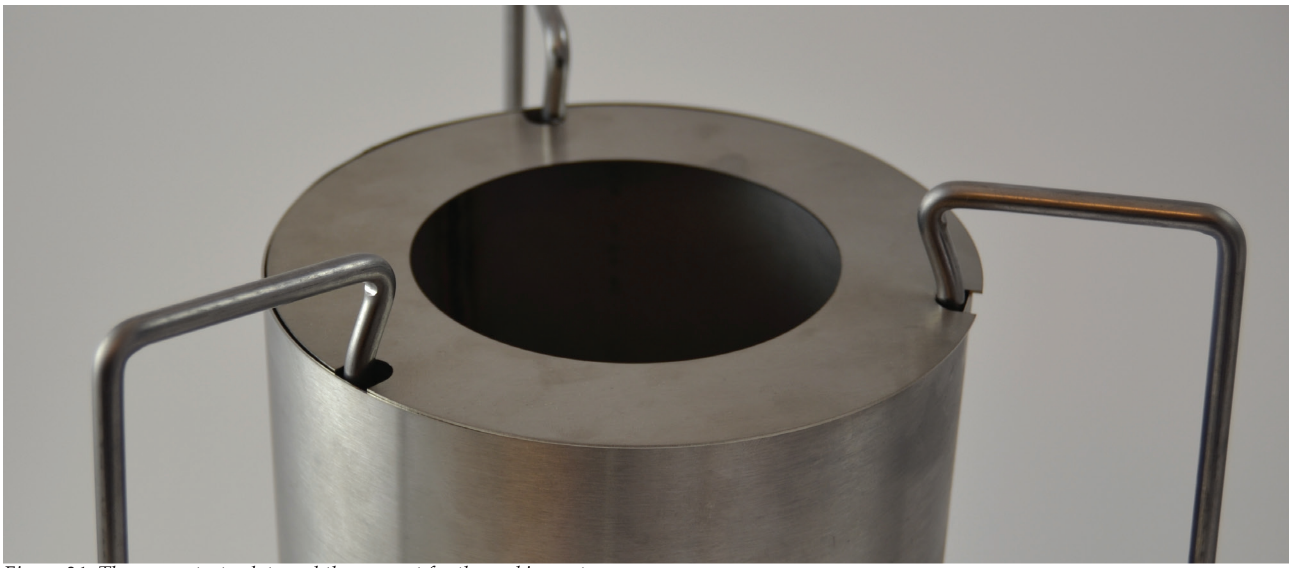


Figure 31. The concentrate plate and the support for the cooking pot.


Figure 32. One of the legs.


Figure 33. The support for the cooking pot.

sensitive it is. To achieve good balance between the size of the flames, not creating to large flames where the heat will disappear into the air and the wind-sensitivity the concentrate plate is 157 mm in outer diameter and 95 mm in inner diameter.


Figure 34. The rack.

The rack consists of one ring and three legs joined together to create the frame of the stove (see figure 34). The rack is made out of 6 mm thick bent rods. The three legs are the support for the pot and the handles which the stove is operated with during use. When the legs and the ring are put together the total height is 305 mm from the ground and the diameter is 300 mm at the widest point, closest to the ground. The legs carry the combustion chamber at a distance of 30 mm above the ground to give some protection against radiating heat created at the bottom of the chamber (see figure 32). It also creates free space for the primary and secondary air supply of the stove. To establish stability in the stove the number of supporting points are crucial. Having to many the stove will wiggle and with too few it will not be able to keep it´s balance. That´s the reason why the stove has three legs but also only three supporting points. To make the stove even more stable the legs are slightly cone shaped which makes it even harder for the center of gravity to fall outside the support surface. It also leaves enough space for the hand to grab the stove without touching the outer casing. The distance between the outer casing and the legs at the closest point is 50 mm. The upper end of the legs supports pot sizes from 115 mm to 260 mm in diameter and is inclined downwards against the middle to provide stability to the pot. It is also 20 mm higher than the inner edge on the combustion chamber to build an air gap between the stove and the pot to avoid that the flames suffocate and maintains the combustion process (see figure 33). The lower parts of the legs are to support the inner casing and fix the position of it together with the outer casing by using the flexibility in the rods to clamp them into place. For stability of the inner cylinder and in order to give a better guidance the point where the forces are located and transferred is placed 40 mm up from the bottom edge (see figure 35). The hook at the end of the legs has two purposes, the first is to lock the inner cylinder to prevent it from falling straight through and the second is to lock the outer cylinder to prevent it from falling down when the stove is standing in it´s up right position. The ring joins the three legs together at the right distance and brings stability to the rack itself. The ring is placed at the end of the legs close to the three supporting points of the stove. Except from the parts mentioned above Hestia also consists of a control handle (see figure 36) to operate the damper and the concentrate plate during use. This is a 6 mm rod with a loop in one end which simplifies the grip.

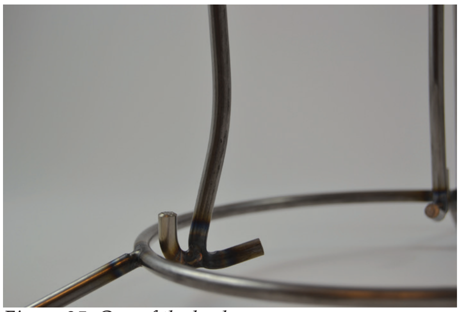


Figure 35. One of the hooks.

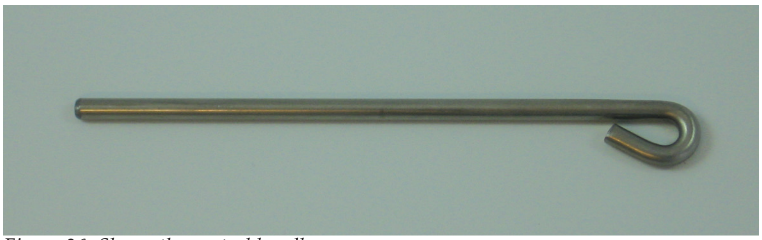


Figure 36. Shows the control handle.


Figure 37. The Outline of Hestia.

8.2 Form

With respect to the form of Hestia the ability of handling and usage has been in focus for the development of the stove throughout the project. This together with an intuitive solution with fewer parts and components which are easy to assemble and easy to reuse. This is done by separating the support and the chamber through letting the inner and outer casing be the combustion chamber and the rack be the support. That gives the user a comfortable and natural attitude to Hestia, how to use it and where to grab. Where three legs/ the rack with multiple functions support and handles in one, gives good performance. One other important focus with the form and the expression of Hestia is stability regarding safe use. The conical shape with the indicated feet and the legs sloping towards the middle give an increased appearance of stability to the stove (see figure 37). The design of Hestia clarifies the different parts and expresses which parts are hot, they are centered in the middle, and which aren´t. This reveals the cool handles which give the users a good approach to handling Hestia when it´s hot. The cylindrical shape of the chamber is to simplify the manufacturing process. It is also because it´s a common shape for stoves, i.e. it fits the users mental picture, and it´s an efficient shape for the pot which has the same shape.

8.3 Materials

The division of Hestia into rack, outer and inner cylinders is not only to facilitate the production and the assembly of the stove but also to customize the materials to the purpose the part shall fulfill. This means that the rack which never come in direct contact with the heat sources and is needed to provide stability to the stove and flexibility to the cylinders can be made of simpler and cheaper steel than the combustion chamber. On the other hand it is important that the cylinder material manages the high temperature which can arise. This makes a more advanced material necessary. The two different materials are iron wire SS1312 or equivalent for the rack and common 0,7 mm stainless steel for the cylinders.

8.4 Assembly

The design of Hestia facilitates the business plan of manufacturing the stove in Sweden, transporting it to Africa and assembling it on site. It can be produced into a flat package (see figure 38) containing all the precut sheet metal, the pre-curved supports and the ring as well as Hestia does not require any screws for the assembly. This makes it easier in Zambia during the assembly process. It requires skills of welding and rolling performance which they already have today. All the sheet metal parts like the two cylinders are laser cut in advance together with the damper and the grid which is also pre-welded and bent into their final shapes. With the rack the ring is bent, pre-welded and the legs are bent as well as the handle. The first thing to assemble which is done by professional at site is to roll the two cylinders and weld the joints together. Next is to fix the bottom to the inner cylinder by welding. After this step the rack can be welded together by freehand but the best result is achieved through building a welding jig and using the jig. The assembly of Hestia for the households is performed by threading the outer casing from below onto the rack through pushing the three inner parts of the supports together. After the outer casing is put in place the combustion chamber needs to be inserted from the top. This also locks the construction of the rack because the inner parts are unable to move. The inner parts are prevented from flexing outwards by the outer casing which is unable to release due to the hooks. They can´t flex inwards either because of the inner cylinder which prevents flexing. The next piece to insert is the damper which is done by dropping it from the top of the stove or bringing it down with the protruding slider faced downwards. Afterwards the grid is placed in the chamber in the same way with the rim down. Afterwards the concentrate plate is put on top, resting on the inner chamber. The only thing left is to put the handle in the slider. With the handle in place the stove can´t fall apart even if it´s turned upside down due to that the handle is attached to the damper which is on the inside of the combustion chamber and the handle is placed underneath the ring of the rack. The design is also adapted to a production in Zambia with local machines and tools for further ambitions and goals. All the metal sheet parts can be cut with metal shears instead of being laser-cut. The bends can be done by hand with primitive tools because they are only bent in two directions.

Figure 38. The precut sheet metal parts.

Figure 39. Unassembled.

Figure 40. The assembled stove.

8.5 Manufacturing cost

The final concept of the stove, Hestia, was presented to Tre D Mekaniska. They answered that they could not produce the rack or the rolling parts on Hestia because they have no access to necessary machines. They still estimated the manufacturing cost for the parts of Hestia which could be produced by them. The price is based on the material choice of common 0,7 mm stainless steel and the pre-made perforated sheet for the grid and a serial production of 500 units. The cost of one unit will be 21 USD plus/minus 2 USD depending on the market price for the stainless steel which fluctuates monthly. After the result from Tre D Mekaniska another company was contacted to produce the rack. The company was Mt svets which is located nearby Tre D Mekaniska who works with prototype productions and total solutions in stainless wire products with CNC controlled machines. They could produce the rack at the price of 8 USD plus 1.5 to 3 USD depending on the surface treatment estimated with a serial production of 500 units and the material SS1312 or equivalent. This gives a total manufacturing cost of 30 USD for Hestia (see page 78) excluding the cost for shipping and assembling. Why the price for Hestia only consider the costs for Sweden is due to that the project aim of design a stove for Zambia which is going to be made in Sweden. The circumstances of not know for sure if it could be assembled by the households themselves or if its needs a local workshop and more exactly how it going to be sold to the people at site.

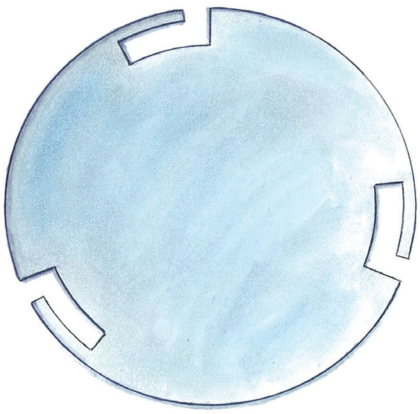


Figure 41. A illustration of the baseplate.

8.6 Price optimization

To reduce the production cost for the cylinders there are overall four things that influence the manufacturing price in the end. The first is the cutting distance, next is number of piercings that the laser needs to cut out. Third is the amount of material spent, the negative part of the sheet is included and also the thickness of the material has an effect on the price picture with an increasing cost for decreasing thickness. The last thing that influence the price is the number of produced units.

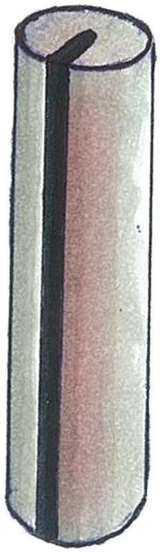


Figure 42. A illustartion of the handle.

8.7 Extra features

Hestia can be extended with a baseplate (see figure 41) to protect the ground from the radiating heat and falling ashes from the damper. The baseplate is placed underneath the combustion chamber and fixed to the three legs by a bayonet socket. It is fixed at a height which creates an air gap on both sides, above and below to cool the ground and avoid direct contact with the ground. Another item that is possible to add is wider handles (see figure 42) for more ergonomic grip. The handles are made out of wood and has a cylindrical shape with a diameter of 18 mm and a height of 120 mm. The attachment needs some modification of the legs to make them asymmetric in the cross section where the handles is placed. The handles have a groove along the side where the asymmetrical legs are inserted to fixate.

9. Evaluation

In the end the result was evaluated by comparing Hestia with the requirements list, developed during the project and evaluating how well it was fulfilled. The result was also evaluated in the Combustion part 3 (see page 60) performed with the new design of the combustion chamber together with a separate evaluation of the final prototype looking from a more manufacturing perspective.

9.1 Fulfillment of requirements

Hestia manage to reduce most of the smoke emissions and reduce the amount of fuel consumption compared with a conventional fire and the Peko Pe design. This is done through control of the heat output and primary air supply which is solved by a damper regulating the primary air. The performed combustion tests confirm that Hestia produces biochar at the end of the usage. With the requirement the focus was to prevent smoke and to get rid of the hazardous particles to solve the health problem with smoke related injuries. Smoke as vapor and carbon dioxide is not the problem and going to be emitted during the incineration process.

The final concept contribute to reducing the burns due to the pot support and the clarity of the design but does not eliminate them. The problem with radiating heat from the bottom is met by a available baseplate which also protects against descending ashes.

The requirement concerning no use of any toxic materials is fulfilled by defining the materials used in the product. The same goes for managing high temperatures. There are no material hybrids within the product either.

Statements from the companies ensure that the cost for Hestia will be about 30 USD which fulfill the requirement and give the new design a benefit compare with other stoves. It could even be reduced at a closer look when determining the surface treatments is done with help from an evaluation at site. The production of Hestia has taken into account the available machines and tools at site in Zambia and does not require any advanced machines or tools which does not exist at place. Even the repair is considered. During assembly of Hestia the need of screws or similar parts are not necessary, only welds and pressure. The amount of different parts the new stove consists of is compared to the reference product Peko Pe. Peko Pe consists of 14 different parts and 14 screws. The new design only consists of 11 parts, no screws and with the extra features 15 parts.

Test result-Time duration	
	Total Burning time (min)
Test 12	15
Test 13	15
Test 14	22

Table 12. Showing the total burning time for the different test.

To fulfill the demand of supporting different pot size the rack is compatible with the most common used pots by the target group. The dimensions of Hestia is set to provide a total amount of three liters solid fuel and the height provides a comfortable sitting position. The grid determined for the combustion chamber has a dimension, mentioned earlier, able to handle pellets size down to 4 mm without any problems. The concept design meets the demand to refill and tap the stove through providing several handles and a removable concentrate plate.

9.2 Combustion part 3

Combustion part 3 consist of test 12, 13 and 14 which were performed with the final design of the combustion chamber. It was done to try out the changes from combustion 2 session and to evaluate the result.

The tests 12 and 13 had a total duration of about 15 min each for the burning time and test 14 had 22 min. The weather conditions during execution of the tests was little wind and about 220 g of eight millimeters pellets were used. The procedure of the ignition was changed a little bitt from the other tests. The test 12 was ignited with pellets soaked in lighting fluid and then paper and at last sawdust. This together with that the damper was fully open resulted in that the ignition step did not occur. Instead the burning time occurred immediately. It was no problem to ignite the stove, it started at once due to this. After the fifteen minutes the flames goes out and the biochar starts convert to ashes. One observation during the test were that the stove smoked a bit in the beginning. Another observation were that the legs became really hot which can increase the risk for burns. For the test 13 the ignition was performed in the same way as in test 12 except from use of light fluid. This was done to reach and try a more authentic use situation. The outcome of this was that it was harder to ignite the stove and it took about 4 min before the stove burned, which in the end depended on the fresh start with light fluid. One reason was that the sawdust burned too fast to allow the pellets to catch fire. After the ignition it was no problems noted regarding the incineration. A bit into the test the damper was used to try to slow down the process and extend the duration of combustion. However, it was hard to know how much the damper had closed because it was impossible to see. An observation afterward was that the damper was completely closed except from one five mm hole, but the stove had to great of a tolerance which led to an overflow of air passing through. Even this time the stove smoked a bit at the end of the test. When test number 14 was performed with the same procedure as in test 12 it was easy to ignite the stove. This lead to that this time the step ignition was not needed and burning time occurred immediately. Shortly after the ignition the damper was reduced and almost closed when there was no risk of the fire going out. The whole test went smoothly without any problems and there was no need for interference. The combustion rate was 0,6 kg pellets per hour. With the 135 mm fuel storage full the stove last approximately 100 minutes.

Regarding to the combustion part 3 session the final result provide a good incineration process and high heat output of the stove. However, the stove needs to be rolled when it´s manufactured to be able to ensure an even and circular shape which gives an even space between the two cylinders. For the rack, to many and to large contact points has to be avoided preventing conducting heat into the support to reduce the risk for burns. With the damper the tolerances has to be high to prevent overflow of air that could pass through and to ensure the effect of the damper when it changes. Also preventing large lateral movements due to that the damper is not fixed in the center. A marking of the damper´s open and close position is also necessary. Broader user study in Zambia would be recommended to confirm this statements.

9.3 Final prototype

The final prototype is as the stove supposed to be in the end except from some few details with the dimensions and tolerances. To facilitate the manufacturing of the stove but also to reduce the price it could be produced in a thicker material, from 0.7 mm to about 1.5 or 2 mm. This would help the parts which are rolled and welded together to prevent from not warping. The increased thickness also facilitate the rolling part, preventing the material revert to original shape. The result from such a change would also improve the enduration of the stove by better resistance against the heat. The heat will release some of stress in the material built up by the welds. The new design is little bit heavier (see page 79) than the smaller Peko Pe but since this never has been a requirement and compared to the Peko Pe it has more functions or handling facilities, for instance the damper, the weight is not an issue. One thing that has not been taken into account in the weight for the Peko Pe is the extra materials for the welded joints or the screws.

10. Discussion

10.1 Process and methods

10.1.1 Data collection

Since the project could not start with a broad and thorough research phase at site in Zambia I needed to trust in a more narrow amount of information from a second-hand source. I could not directly confirm this information with the end-users. This has made it harder to find information like habits or manners regarding the user behavior. One more thing that has done the research harder and can affected the result is that the most literature or text not particular concerns Zambia. Since cooking can differ between countries it can be an issue that I haven´t been in Zambia to observe their customs. On the other hand I have succeed to reach prime information regarding the technology and the stove when I talked to the founders of top-lid updraft gasifiers. I have also had contact with one of the persons providing the pellets at site living in Zambia. This has been a choice since the project aim was to come up with a stove design as close to production as possible in the end. The big problem today is that the most implementation programs has failed after a couple of years of use. I want to prevent this by evaluate the new design on site with a functional prototype together with the target group to be able to catch problems with the stove. In this way I can report improvements and recommendations that will be needed for further success and in long term use.

The data collection phase was also affected by the urgent need of producing a concept in an early stage of the project. This to convince the company Tre D Mekaniska to participate in the project which has influenced the whole process. My schedule was offset due to this. Afterwards it kept going in two parallel tracks, one close to the company Tre D Mekaniska and one more classic design development process. This has kept the project close to reality and the possibility to manufacture. I think this has in some ways prevented it to be really innovative and imaginative or at least made it harder to express it into ideas. The idea generating has also been affected by the idea quantity together with achieving a stove design ready for production. Another thing that could have effected the result in the end or on the number of ideas where the lack of collaboration with others during idea generating phase by implementing a focus group or similar method. However, I had good help of the image board of the grills and theirs expression as products and morphology matrix.

10.1.2 Different actors

Working for one company, cooperate with another company and in the same time do it as a master thesis for the school has been inspiring and educational. The biggest challenge has been to be innovative but still get the company Tre D Mekaniska to approve the design with their focus on production ability and manufacturing costs. It has been necessary to collaborate with them or a similar company to be able to get as far as to the manufacturing phase. One other aspect and a challenge with the collaboration has been the knowledge of understanding how different things works within the different partners. Vagga till Vagga has knowledge about the environment, the social aspects and the pellets production in Zambia, Tre D Mekaniska know the manufacturing processes and me who knows about the theory scientific part and act as middle hand between the two.

10.1.3 Physical models

The choice of working hands on in an iterative process with physical models felt necessary since I never worked with incineration before. This has done that I have not performed any calculations regarding the flow and how it affects the process for different shapes and configurations on the stove. I have trust the fact revealing that my stove is better than a regular open fire and the stoves they use today. But it has never felt needed to calculate how much better it would be with my particular stove only that it´s better. Instead I have observed the result during the preformed tests, which reveals that it´s at least as good as the Peko Pe and even better. This choice has also depended on the fact that the thesis has not been focused on flows and incinerations it has instead been about the design. The design has definitely affected the work and it would have been good to perform boiling test and lasting test in order to better compare my stove to the others. The choice of working practical has also depended on the technique aspect of TLUD process. This process is a quite young combustion method which only has exist in about 35 year compare with many other methods and the open fire itself. This together with that it doesn´t exist any patents for the stove which has led to that it´s an overflow with homemade products and solution on the market especially in the USA. The theory is both scanty and varying in the sense of using it as a base for product development. The hardest part of working with physical models is to be sure about a certain event that appears and to draw conclusions from it. That it isn´t something that accidentally occurs during one test. This made me perform two similar tests almost each time. However, when something occur it´s often easy to detect with physical tests, as with the test of the Cone prototype. This test immediately revealed that it was bad combustion. It felt also good to perform the test in the reality with various types of weather conditions outdoors for a more authentic situation. In this way problems with high lab result which are not transferable in daily life usage are avoided.

10.1.4 Environment aspects

The focus on sustainability and cradle to cradle in the project has not been as thorough concerning different materials and alloys as it could have been trying to find totally environment friendly alternative. This is due to the demands on market price for the stove. The price has been crucial for the target group and the possibility to compete with the competitors. This led to that almost all focus has been on the functionality and the social aspects of the stove. But also the most basic aspects of C2C such as health for the users and the people in the closest surroundings. This involves both toxic and harmful materials used in the product together with what its releases or emits within the process during use. Working from the requirements of not creating any smoke emissions during ignition and extinguishing has been hard due to that is a matter of the incineration process. Only in perfect conditions complete combustion occur which will never be the case here. My help has been the combustion tests and the expert consultations which has guided me to a respectable result.

10.1.5 Materials

In this project I have not worked particular with other materials for the stove than different steels. This is because of my aim to take the design to production phase and the early collaboration with Tre D Mekaniska. They was set to be the manufacturer of the stove due to their skills in processing different kinds of steels and alloys. I have thought of other materials like clay and got inspired by other stoves which are made out of ceramics or have it as an insulation material to improve the incineration. To use ceramics or simple clay to make the stove would reduce the cost of it. During the World Bioenergy 2012 I got the idea of using ceramics to increase the efficiency of the stove. But it would increase the cost of the stove using one more material like ceramics as an insulation. Also the weight of the stove is considered since it´s going to be transported. Therefor ceramic was rejected in the end.

10.1.6 Being on my own

During the project regarding of being on my own every decision has been a struggle since it was not possible to discuss and argue from an concept or idea. I had to rely on methods used for the purpose or what the expert consultation resulted in. If that not resulted in a single concept or idea the trust need to be in myself and my professionality. On the other hand I have take all the decision and been present in each and every one of them. I had to push the project forward and not to get stuck at a phase. However, being on my own has have the advantages of been able to easier structuring my work after actors and the different steps within the design process. It has also been easier when some unexpected event occurs or changes that needed to be done.

10.1.7 Concept selection

The concept selection was performed together with Vagga till Vagga and not with Tre D Mekaniska. This decision was made to prevent an early limitation for which idea to continue with respect to the manufacturing possibility point of view. That is more than what already has been done so far with the Cone and the Rods. The focus with the project was selected to design a stove with social and environment aspects. The decision of which concept to further develop was based on pros and cons for each concept. The pros and cons is conclusions from the theory, the practical tests, the requirements list, the statement from Tre D Mekaniska and the expert consultation. But no further calculations regarding the cost for each of concept or on the manufacturing of them were done to support the decision. On the other hand after talked to many different persons, like those mentioned above, I had quite good knowledge what was possible in terms of both manufacturing and price regarding the concepts to be able to compare them.

10.1.8 Vagga till Vagga

Working with Vagga till Vagga has been both fun and good in many aspects like during data collection to gather information, using their contact network and for tutorial. Through the whole project I have focused to develop a stove aiming to be produced in Sweden and shipped to Zambia for assembly. But in the long term the idea is that it should be both manufactured and assembled on site which I had tried to always have in mind during the process. I have tried to adept the stove and the assemble for production in Zambia which not always has been so easy and this might have had an inhibitory affect for the innovation. However, it is positive for realization of the part in the end and the aim of being a long term solution.

10.2 Result

With Hestia I wanted to create a stove that could compete with the other stoves on the market by price and simplicity. I´m confident to have succeeded to design such a stove but also fulfilled all other aims for the project. With the result I have designed a stove which not only manages combustion of biomass for cooking. I have also made it easier to control the heat output which is an advantage compared to many of the competitors, especially the ones without the fan assisted draft. Using a smaller diameter for the combustion chamber than the Peko Pe together with the damper, the fuel consumption has been reduced compared to the measured rate of the Peko Pe. Hestia have been designed with respect to the ability of handling and usage. For example the three legs with the multi functions as support and handles included in one gives me the courage to assure the user of its good performance.

10.2.1 Safety

Safety has been a big issue throughout the project. This I have handled in different ways. The design of Hestia is done so that it clarifies what the different parts express. The parts which are hot are centered in the middle and the parts which are not hot aren´t. Hestia´s cone shape which is created by using indicated feet and the sloping legs towards the middle gives a clearly stable expression and construction. The competitor´s stoves gives more of a unstable impression, where many of them are quite high and thin. Due to the indicated feet the combustion chamber is also separated from the ground which gives a natural possibility for air cooling and placement of a protection sheet. Still there is some lack of good protection against burns form hot liquid for almost all stoves today. Now the pot support, with its angle towards the middle, creates a burn protection which has some ability to adapt to differences and can be changed to better fit the reality. It is still not perfectly achieved but it was decided that the needed distance between the inner and outer casing would be too large considering the cost for the extra material and the size of the stove using only air as cooling element.

10.2.2 Design and sustainability

From a design and a sustainability perspective I believe I have succeeded designing an intuitive solution with less parts and assembly components than the competitors. Resulting in an easy assembly and an easy reuse opportunity of the different materials at the end. Where the selected materials well meet the needs of the criteria for the purpose of the task of a certain part. However, the intuitive solutions like with the damper with no connection point could have a negative effect on the incineration process. This could be prevented by putting higher demands on the craftsmanship during manufacturing but will probably result in that it lasts longer.

10.2.3 Design choice

One issue in the end is that Vagga till Vagga has chosen another design for their stove than Hestia to continue with which has affected the project in terms of lack of an extensive evaluation. They succeeded to find a stove which already is produced at site in Africa. The thorough evaluation of my stove design in the project was not done according to plan since the intention to visit Zambia and the target group to get their opinion will not become reality within the project, this because lack of money. I would like to evaluate the numbers of support points for Hestia to test if it is enough with three supports for the pot or if it needs four, to see which is best. Further, the materials for the outer cylinder needs to be evaluated to see if it is possible to change that to a less expensive material than stainless steel. However, it can result in that the wall thickness needs to be increased to be as rigid as the stainless steel. But it can also result in a heavier stove.

11. Conclusion

The purpose of this project has been to design a new stove for the urban areas in Zambia to help them with better cooking technology in every day use. The main aim has been to produce a stove ready for manufacturing which use pellets as solid fuel produced from waste products like sawdust. The final concept, Hestia, is stoves for cooking meal in a single pot with the possibility of regulating the primary air supply for better adaptation and incineration. It is produced in stainless steel and mild steel to suit both the inevitable heat evolution from the incineration and local production conditions in Zambia. Using natural convection to combust the secondary gases to produce the heat output. The easy assembly without any pieces for joining puts low requirements on necessary machines and tools needed for the practitioner. This together with the pre-made stove parts packed in flat packages makes Hestia easy to export to different areas. Hestia is easy to use and to operate with help of the three legs which provides sufficient space for the hands to avoid touching the hot casing. The three legs also provides a more stable construction with less need of a flat ground to rest on. The design helps to save both life and environment through preventing the forest to be cut down for use of fuel in large scale and by creating almost no smoke emissions during usage. It is possible to implement the solution on the market today.

12. Reference

12.1 Websites

Trail Designs, 2007-2012. Trail Designs. [online] Available at: http://www.traildesigns.com/ [Accessed 17 December 2012].

M. S. Tembo, 2012. Nshima and Ndiwo Zambian Staple Food. [online] Available at: http://people.bridgewater.edu/~mtembo/menu/nshima/nshima.shtml [Accessed 17 December 2012].

Zambia Tourism Board, 2012. The People of Zambia. [online] Available at: http://www.zambiatourism.com/travel/hisgeopeop/people.htm [Accessed 17 December 2012].

Countries and Their Cultures, 2012. Zambia. [online] Available at: http://www.everyculture.com/To-Z/Zambia.html [Accessed 17 December 2012].

Central Intelligence Agency, 2012. The World Factbook - Zambia. [online] Available at: https://www.cia.gov/library/publications/the-world-factbook/geos/za.html [Accessed 17 December 2012].

Republic of Zambia Central Statistical Office, 2000. Housing and Household Characteristics Analytical Report. [online] Available at: http://www.zamstats.gov.zm/media/hse_rpt.pdf [Accessed 17 December 2012].

World Health Organization, 2012. Burns. [online] Available at: http://www.who.int/violence_injury_prevention/other_injury/burns/en/index.html [Accessed 17 December 2012].

Dr TULD P. S. Anderson, 2012. TChar Technology for Cookstoves (Paper series). [online] Available at: http://www.drtlud.com/2012/08/02/tchar-tech-paper-series/ [Accessed 17 December 2012].

giz HERA - Poverty-oriented Basic Energy Service, 2011. Micro Gasification: Cooking with gas from biomass. [online] (January 2011) Available at: http://www.newdawnengineering.com/website/library/Publications/HERA-GIZ%20micro-gasification%20manual%20V1.0%20January%202011.pdf [Accessed 17 December 2012].

Vagga till Vagga, 2012. Biochar. [online] Available at: http://vaggatillvagga.se/ [Accessed 1 February 2013].

International Biochar Initiaive, 2012. What is biochar? [online] Available at: http://www.biochar-international.org/ [Accessed 1 February 2013].

Environmental Protection Encouragement Agency, 2013. Cradle to cradle. [online] Available at: http://epea-hamburg.org/index.php [Accessed 29 May 2013].

Environmental Protection Encouragement Agency, 2013. EPEA Gmbh. [online] Available at: http://epea-hamburg.org/index.php [Accessed 29 May 2013].

Eva solo, 2013. Products, Uteliv. [online] Available at: www.evasolo.com [Accessed 13 June 2013].

Ezy stove. 2013. Ezy stove. [online] Available at: www.ezystove.com [Accessed 13 June 2013].

12.2 Articles

H. S. Mukunda, S. Dasappa, P. J. Paul, N. K. S. Rajan, M. Yagnaraman, D. R. Kumar and M. Deogaonkar, 2010. Gasifier Stoves - science, technology and field outreach. *Current Science,* 98(5), p.627.

J. E. Sinton, K. R. Smith, J. W. Peabody, L. Yaping, Z. Xiliang, R. Edwards, and G. Quan, 2004. An assessment of programs to promote improved household stoves in China. *Energy for Sustainable Development,* 8(3), p.33.

R. Hanna, E. Duflo and M. Greenstone, 2012. Up in Smoke: The Influence of Household Behavior on the Long-Run Impact of Improved Cooking Stoves. Cambridge: Massachusetts Institute of Technology.

G. Bensh and J. Peters, 2012. A Recipe for Success? Randomized Free Distribution Improved Cooking Stoves in Senegal. Ruhr *Economic Papers,* 325.

D. F. Barnes, K. Openshaw, K. R. Smith and R. V. D. Plas, 1994. What Makes People Cook with Improved Biomass Stoves? A Comparative International Review of Stove Programs. *World Bank Technical Paper,* 242.

V. W. Cappelen, 2012. (in press) Peko Pe Manual.

P. Löfberg, and M. Olsson, 2012. (in press) Business plan - Replacing firewood and charcoal for cooking, with waste biomass pellets.

P. Löfberg, and M. Olsson, 2012. (in press) Baseline survey MOS - draft.

C. Roth, 2012. (in press) Final report Malawi TLUD project supported by ECPF. Eschborn:

D. Amosy, F. Axelsson, H. Hasselqvist, and M. Renström, 2010. A BURNING NEED - Preventing burn injuries among children. Gothenburg: Chalmers University of Technology.

A. Engström, E. Österdahl, 2011. Cleaning Africa through product design - a field study regarding plastic recycling and sustainable product development in Zanzibar. Gothenburg: Chalmers University of Technology.

M.-A. Karlsson, 2011. (in press) Industrial Design Engineering Methods and Tools.

L.-O. Bligård and A.-L. Osvalder, 2007. An Analytical Approach for Predicting and Identifying Use Error and Usability Problem. *HCI and Usability for Medicine and Health Care, 4799. p 427-440.*

E.Y.-L. Do, 2005. 'Design sketches & sketch design tools', *Knowledge Based Systems,* vol. 18 iss. 3, p 383-405.

12.3 Books

K. Ulrich, and S. Eppinger, 2012. *Product design and development* [5:th ed]. New York: McGraw-Hill.

K. Österlin, 2003. Design i fokus för produktutveckling. Malmö: Liber

12.4 Contacts

H. Thunman, 2012. [email] (Personal communication, 20 september 2012).

N. Vahlne, 2012. [conversation] (Personal communication, 3 september 2012).

G. Brännare, 2012. [conversation] (Personal communication, 28 august 2012).

M. Norell, 2012. [phone call] (Personal communication, 5 september 2012).

A. Kinnander, 2012. [phone call] (Personal communication, 18 september 2012).

S. Kauti, 2012. [Skype call] (Personal communication, 5 may 2012).

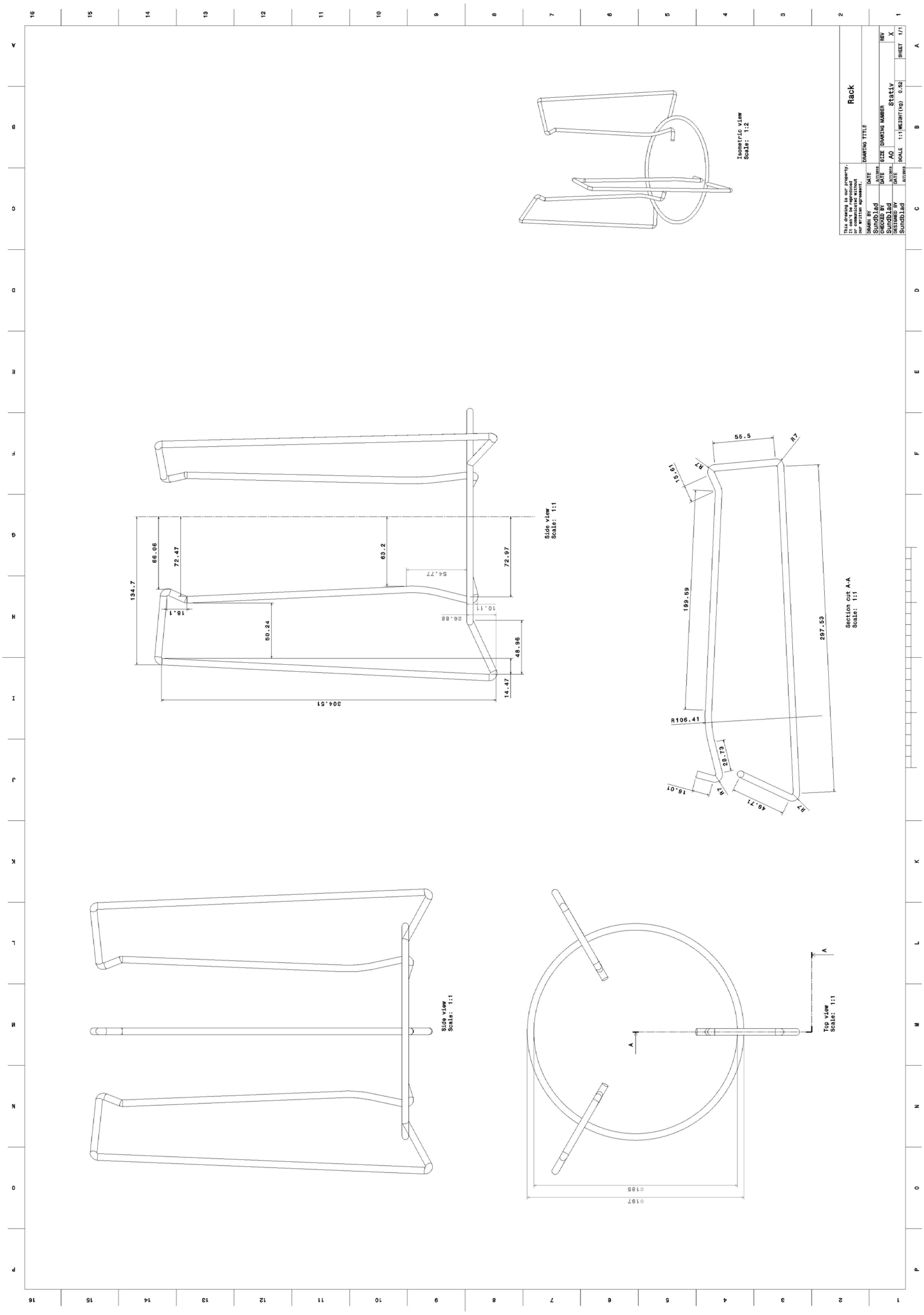
P. S. Anderson, 2012. [Skype call] (Personal communication, 15 may 2012).

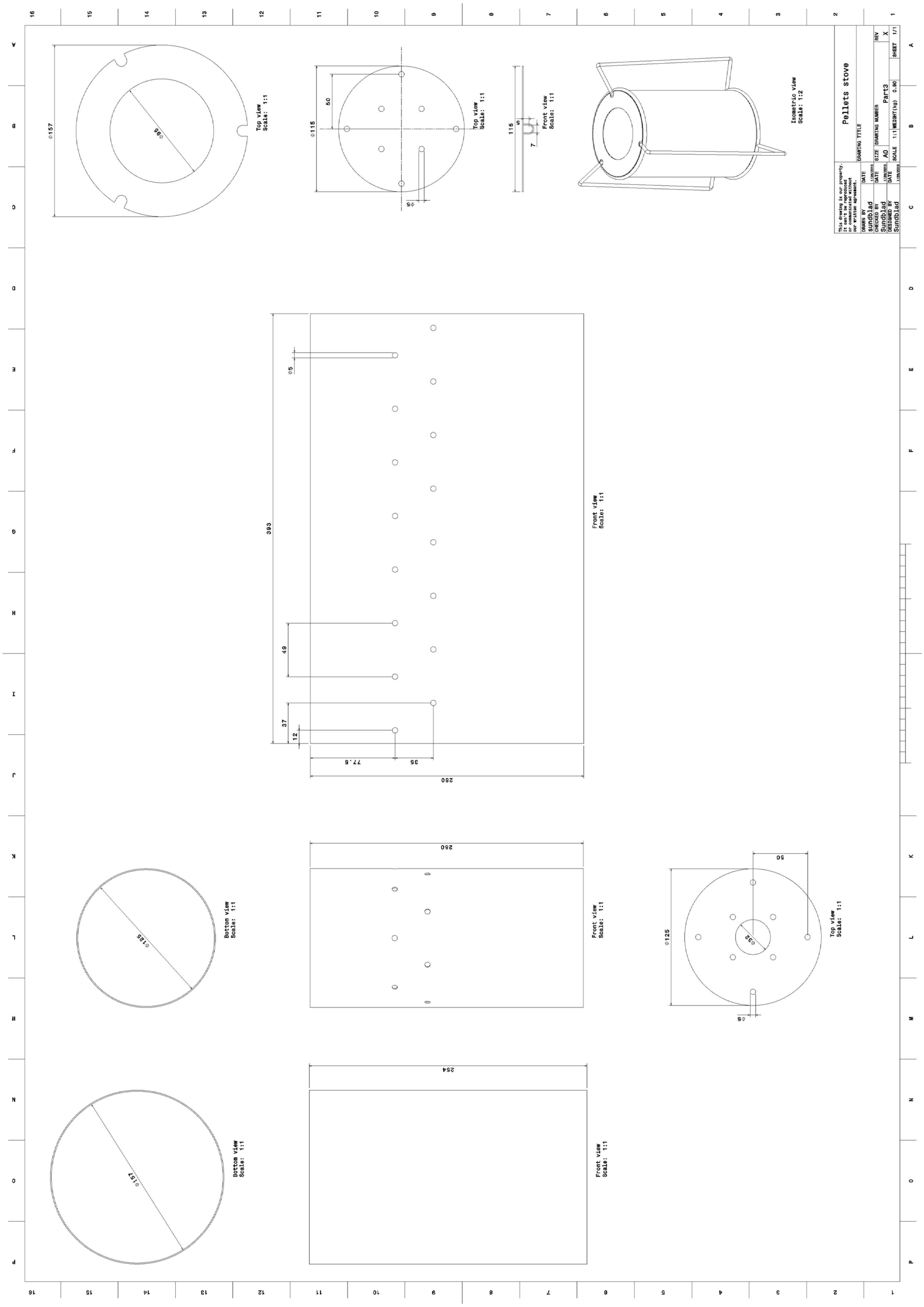
C. Roth, 2012. [conversation] (Personal communication, 15 February 2012).

12.5 Events

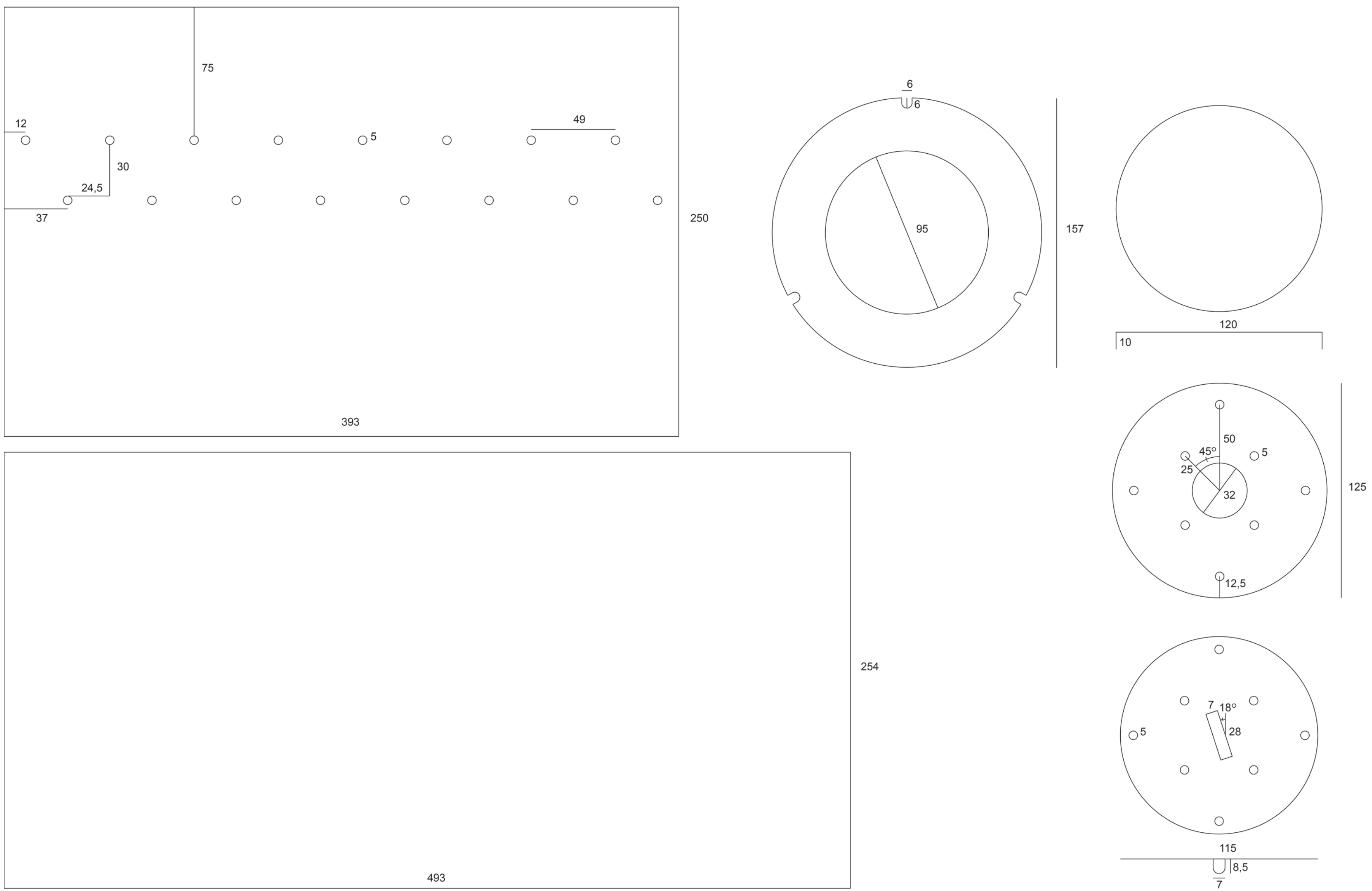
World Bioenergy 2012, 2012. World Bioenergy 2012 - Conference & Exhibition on Biomass for Energy. Jönköping, Sweden 29 May 2012. Elmia

Appendix 1: Drawings




Pellets stove
Part3
Sundblad
Top view
Scale: 1:1
Front view
Scale: 1:1
Isometric view
Scale: 1:2
Bottom view
Scale: 1:1

All measurements are in mm.



Appendix 2: Cost estimates

Expense Tre D Mekaniska		
Complete chamber: 500 pcs:	144 SEK / unit +/- 15 SEK Manufacturing cost - 10%	21 USD +/- 2
Expense Mt Svets		
Complete rack: 500 pcs:	50 SEK / unit + (10-20) SEK surface treatment + 2000 SEK welding rig 50 + 20 + 4 = 74 SEK	8 USD + (1.5 - 3)

Appendix 3: Weight

Components	**Final Prototype (g)**	**Peko Pe (g)**
Chamber: Damper: Grid: Outer casing: Rack: Concentrate plate: Handle:	590 57 76 672 620 64 55	553 Do not exist Do not exist 711 153 (legs) 113 Do not exist
Total	2135	1610

Appendix 4: Interview with Paul Andersson

- **At which hight should the primary air intake be?**

The premiere air intake need to be in the bottom of the inner cylinder too supply the stove with plenty of air to get a efficient natural draft. It doesn´t work with only a road of premiere hole on the side like on the wood camp stove due to that stove have a fan to circulate the air and gases. But it´s necessary to be able to control the premiere air supply after demand.

- **How much primary air is required?**

In the beginning there need to be allot to support the fire but in the end there is not quite as important, that why the premiere air needed to be adjustable.

- **How much space must it be between inner- and outer casing?**

Around 1 inch between inner- and outer cylinder, maybe there need to be bigger to be able to support a lager pot if the outer cylinder is used for pot support.

- **In ”Technology for Cookstoves” parts C, D and E are mentioned. Do they exist?**

Read booklet E.

- **At what speed is the pyrolysis front moving using pellets as fuel?**

A container which is 20 cm instead of 10 cm burns twice as long.

- **Will the teperature be 600 to 700 degrees in the stove?**

To get a efficient pyrolytic burning the temperature need to be 450 degrees and it can rise up to 600 degrees within the camber and even more where the gases burns, 700 to 800 degrees.

The diameter that he prefer is 5-6 inch for the T-char if pellets going to be the fuel. But he think that I should test with a tin-can and see for my self and for that case the diameter should be 3-4 inch. He believes that there is a market for small stove especially in the rest of the world like her in Europe. The upper part, 2-3 inch, of the container should not have any hole then there is one too two road of hole for the secondary air. Next part where the fuel contains should be 10 or 20 cm depending how much fuel you want to load for one batch.

It´s can be hard to ignite so dens fuel as pellets so a tips is to use smaller wood chips that are soaked with light fluid rather then try to use light fluid straight on to the pellets due to that they are so dens.

Appendix 5: Interview with Sonta Kauti

- **How dark will it be in the house, is light needed?**

The light today is very inefficient and they use a lot of candles to produce light. So if I could provide with light from the stove that had been a great effort.

- **How does people in Zambia cook, are they standing, standing bent over or sitting?**

The most people sits down due to the short stoves.

- **Is it better to refill the stove often with pellets or that the stove is dimensioned four 3 h burning time?**

Beans takes about 3 to 4 hours to cook. So they need to be able to load proper with fuel. It´s better that it can contain with fuel to support up to 3 h cooking then the other a way around.

- **Are they cooking indoors or outdoors in Zambia?**

The most times the food are cooked outside but sometime they cook inside to collect the heat from the stove in the nights.

- **Is their any resale value for the stove? Or will the material be used for other purposes?**

In the most cases the stoves are throw away in the ends of there lifetime. It exists material dealers that can give some pay for the materials if it´s recycled.

- **Is there a point or need for disassemble the stove?**

That should be when or if the stove is recycled.

- **How well must the stove resist corrosion?**

It´s good if it´s corrosion resistant due to the sentimental value of the stove for the woman's. it´s sees as a higher range among households to have fine stove.

Complains form the people in zambia:
The stove needs two handles.
The handles gets really hot.
The support are inefficient to hold the pot they need to have larger area to support it.

Appendix 6: Early Design

Tre D Mekaniska

Tre D Mekaniska was contacted by Vagga till Vagga in the beginning of the project to assist with knowledge and performance of processing the physical product. The purpose with this was that they should be the partners who produced the stoves in the end. The funding of the manufacturing and the materials was also supposed to be supported by the company together with the municipality.

First concept development

To be able to convince Tre D Mekaniska to be part of the project it was necessary to produce an early design concept which they could use as an calculation basis in order to draw conclusions regarding the possibility of a cooperation.

Idea generation

The first concept was developed during the first weeks of the project and the main idea was created during and was a result off the meeting with the company (Tre D Mekaniska) before the master thesis was confirmed. The meeting was held at the company Tre D Mekaniska and during the meeting the majority of the persons who have been involved in the process were represented, Tre D Mekaniska, Vagga till Vagga, Christa Roth and Filip Sundblad. The idea generation focused mainly on the details of the stove since the main features already was more or less decided on since all were quite consistent of the cone as the main shape from the beginning. An attempt to press the time frame for a delivery was also done. The details discussed were pot support, handles, how the inner and the outer cone should connect to each other and if it will be necessary to be possible to disassemble the cones and how that should be solved. The main feature was based on an idea that the fuel should have the same concentration through the entire burning due to the fuel continuously reduce it´s mass and volume during the whole process should enhance the combustion.

Presentation for Tre D Mekaniska I

The result from the idea generation (see page 37) was compiled with a couple of sketches in Photoshop that describe what the stove looks like assembled, what the outer cone is supposed to look like as well as the inner cone (see figure 43 and figure 44). A simpler drawing and description of all different components was also produced to give the company a basis for calculation and an overview of the amount of material which is going to be needed for manufacturing. All the material was presented for Tre D Mekaniska by mail.

Tre D Mekaniska´s answer to the mail was at first, to the whole project, that they though it looked promising and they stayed positive to it deciding to continue with a cooperation. At the second moment the answer regarding the concept was that it would be too expensive to produce and manufacture the stove mostly since they would need to invest in a new roller machine which is capable of producing cone shapes. Because the zero series is quite small the number of stoves which shall support the cost make the unit price rise too much. It would be too expensive for the people in Zambia and the project would fall before it had even started.

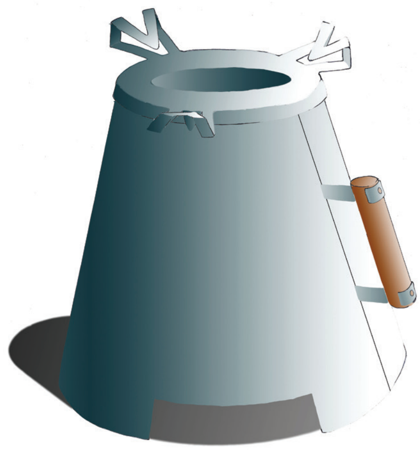


Figure 43. Photoshop sketch of the prototype used for the presenation.

Prototype

The prototype was necessary to make because the cone could not be rejected only from the argument that it should be too expensive to produce without considering the combustion process outcome.

To be able to make the Cone a contact persons in a workshop who also is a friend was asked to produce it. Before the new workshop could make the prototype the cone concept was stripped to get rid of unnecessary parts which are not needed to perform a combustion test such as the pot support and handle. This was done to facilitate the manufacturing process and reduce the workload for the contact. To perform a basis for the model which they needed to produce the prototype computer aided design (CAD) was used as a tool to make a complete drawing in Auto CAD.

CAD is a tool to build and visualize products digitally to create an idea about how a product is going to be perceived in reality. CAD a powerful tool which can be used in many different areas for many different purposes. Some examples of what it can produce are calculations, simulations, estimations, drawings and presentations. Departments that are using the tool today are design, construction, architectures and manufacturing. With the tool it´s easy to change the characteristics of an object to try out different possibilities and vary the outcome (K. Ulrich, and S. Eppinger, 2012).

The drawings together with a discussion regarding the materials which are going to be used and would be necessary was held for the purpose of future combustion tests. It was decided that

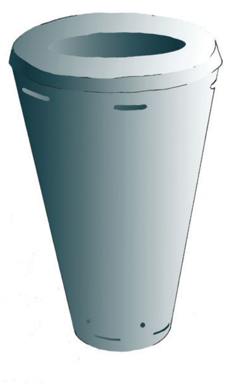


Figure 44. Photoshop sketch of the prototype inner cylinder used for the presenation.


Figure 45. The prototype of the cone.

body panel should be used as material for the cones because the stove only needed to last a couple of tests. The drawing was also decided to be changed to better precise that the different plates: the bottom, the flange and the concentrate plate should fit in each other and be cut out from the same piece of sheet. It was also decided that all the joints will be welded together to facilitate the production instead of making a rim which can be used for assembly and unassembly of the cones.

The prototype produced by the contact was almost exactly the prototype which was expected and followed the drawing well.

Combustion test Prototype

Two combustion tests were conducted with the cone shaped prototype to try out how it´s performance appear in practice compared to the theoretical outcome from the expert consultation with Henrik Thunman (see page 43).

Both the test were performed in windy weather conditions and their total burning time had a duration of zero minutes up to twenty minutes. The result of the first test was that the phase of burning time never occurred during the whole test. It was really hard to ignite the stove and for the 25 min which was attempted it never took fire. During most of the time new pre-ignited paper was needed to sustain the combustion process. When the stove was hot enough the paper was changed to more or less constant blowing to keep the open flames burning. After 25 min of trying to ignite the stove the test was canceled. Two other observations from the test were that almost all pellets were untouched when the stove was emptied in the end. The next observation which was a positive thing was that the bottom of the prototype never got too hot. It was always possible to touch and grab it without getting burned. But in the upper part where the secondary in draft sits it became far too hot to touch. The next test was performed with a small modification in the form of a grid which was used to build an air gap between the primary air intake and the fuel bed to provide a more even spread of air flow. This resulted in better result for the combustion where all the three steps occurred. It was still hard to ignite the stove which took about fifteen minutes to get it burning with open flames. During the burning time step the stove burned with quite calm flames and a couples of times they passed out due to the wind and extra blowing was necessary. In the end when the flames were extinct the combustion process continued converting biochar into ash without any smoke emission. But this process was stopped after 10 min. Even this time the stove´s bottom never became too hot to grab and the upper part on other hand became dangerously hot.


Figure 46. Visual resualt from the two test with the prototype . First test at the left and second one at the right.