BIOCHARGER

A TRANSPORTABLE BIOCHAR KILN

Mini Dissertation Research Document

Biocharger: The Design of a Safe and Efficient Biochar Production Unit for a Small Business Initiative in Johannesburg, Gauteng.

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Abstract:

The aim of this research study was to design a safe and efficient biochar production unit to be used by employees of a small business in Johnnesburg, South Africa. The study also aimed to design a system of operation for the business which could improve access to biocahar for the urban farming community of Johannesburg. The design of the biochar production unit, and the system of operation for the small business, were informed by qualitative data obtained from field research as well as a literature review. The research study adopted a pragmatic approach to the field research which falls under the methodology of participatory technology development (PTD). Field research was conducted with a government initiative called the Working for Water (WfW) programme. The WfW programme is responsible for the management of invasive alien plant species (IAPs) in South Africa, which is considered a potential natural resource input for the manufacture of biochar. The literature review concerns the relevant topics of biochar science and technology, natural resource management in the context of South Africa, and charcoal production and technology. The field research identified that, currently, there is a large amount of waste biomass on clearance sites previously managed by the WfW programme. This biomass is a potential fire hazard, a haven for rodents, and an obstruction to the meaningful use of the land. The designed system of operation for the business establishes that the business will provide a value proposition by removing the biomass from the land by converting it into biochar. The biochar may be sold in bulk to local compost manufacturers and the income of the sale of this biochar may be used to sustain the operation of the small business. The small business will employ members of local, marginalised communities to operate the biochar production units on site where the biomass has accumulated. With the expansion of the business, and the long term goal of financial self-sustainability, there is a higher chance of success that biochar could be made available to urban farmers from a controlled and reliable source.

Keywords:

Industrial Design, South Africa, Transportable Biochar Kiln, Gauteng Department of Agriculture and Rural Development, Working for Water, Siyakhana, Natural Resource Management, Invasive Alien Plants, Urban Agriculture.

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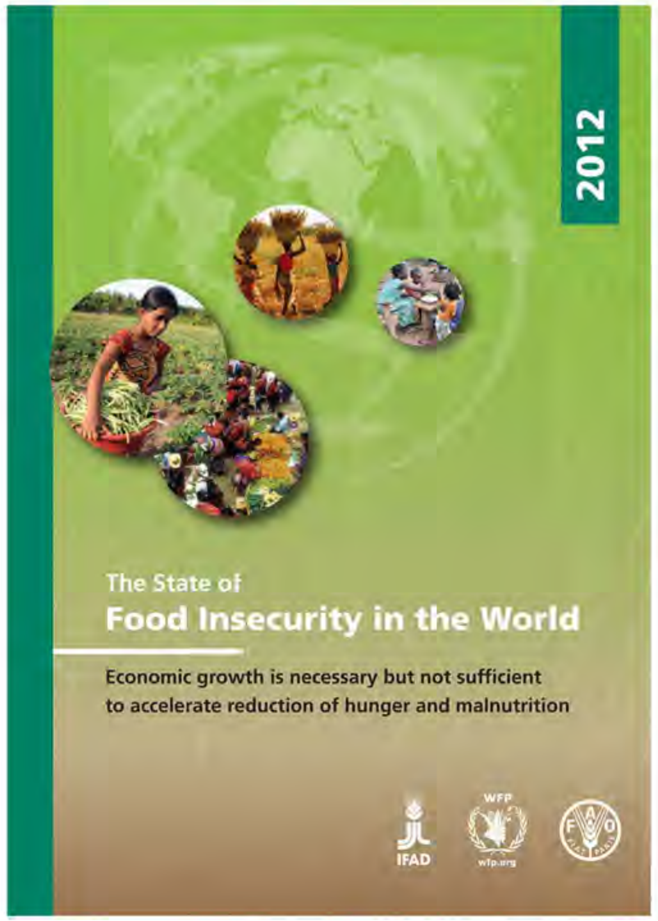

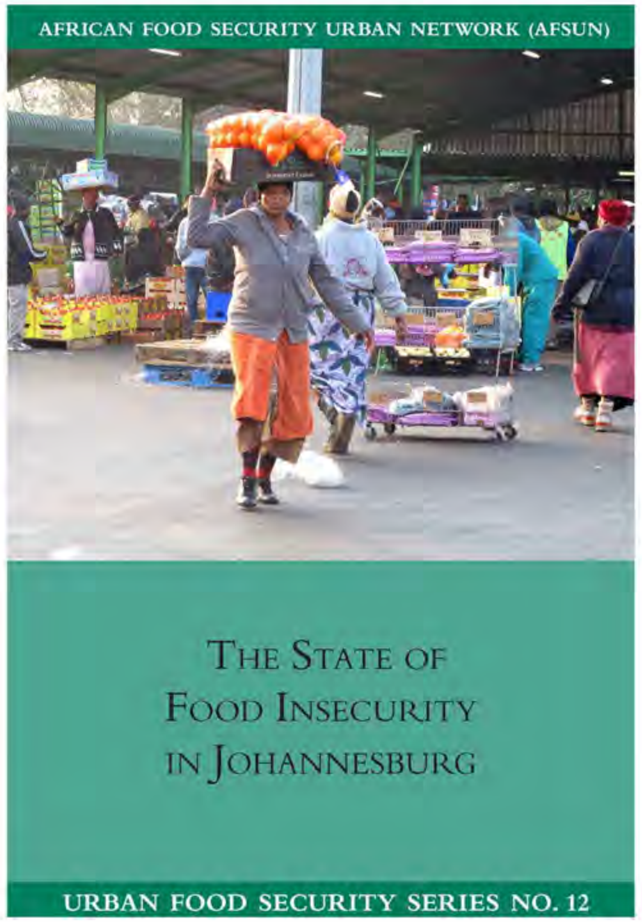

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Chapter 1: Introduction

1.1. Outline of the Study

According to a publication by the Food and Agricultural Organization of the United Nations (FAO) entitled *The State of Food Insecurity in the World 2012*, the "number of hungry people in the world is unacceptably high... [and] the vast majority live in developing countries" (FAO 2012: 2). A study conducted by the Development Bank of Southern Africa, entitled *Urban Food Security in South Africa: Case Study of Cape Town, Msunduzi and Johannesburg*, shows that a majority of households in marginalised communities of these cities rely on "informal market[s] and street food [vendors]" as a source of access to food (Frayne *et al* 2009: 31). This is supported by a study published by the African Food Security Urban Network (AFSUN) entitled *The State of Food Insecurity in Johannesburg*, which states that individuals from marginalised communities in Johannesburg frequent informal vendors on a daily or weekly basis (Rudolph *et al* 2012: 26). The study suggests that this trend is related to "long-distance commuting within the city... the difficulty and cost of [buying and] transporting large volumes of food from supermarkets, and to inadequate cold storage in households" (Rudolph *et al* 2012: 26). Ironically, informal market and street food traders may also struggle with transport of their stock, as well as keeping certain perishable foods fresh. As a result, the "dietary diversity" (Frayne *et al* 2009: 21) of patrons of these traders may be limited to the nutritional value of foods which are suitable for the informal market and roadside environment. A survey conducted in marginalised communities of Cape Town, Msunduzi and Johannesburg revealed that 10% of the people surveyed had "one or more chronic diseases associated with a modern, urban lifestyle...[and were related to] a lack of dietary diversity, overweight and obesity, and a sedentary lifestyle" (Frayne *et al* 2009: 21). The mayor of Johannesburg, Parks Tau "reported that 22% of the city's population were categorised as poor and, of these, 42%, or 420 000 people, were food insecure" (Moolman 2013: [sp]). Tau states that, ""As a result, food security and urban agriculture have become a critical part of the programmes that we pursue as the City of Johannesburg. We believe we should set ourselves an objective to build a city where no one goes hungry"" (Moolman 2013: [sp]).

In addition to informal markets and street food vendors, it is said that "small- and medium-scale food producers in the urban and peri-urban context could contribute significantly to improving food availability and the resilience of food systems in Gauteng, thereby helping to address food insecurity" (Siyakhana 2012: 1). A report released by the Gauteng Department of Economic Development (GDED), entitled *A Strategy for a Developmental Green Economy for Gauteng*, states that an estimate of "449,800 jobs [could be created for people in Gauteng through] investment into basic infrastructure, capacity building and support" for urban based agriculture (Spencer *et al* 2010: 42).

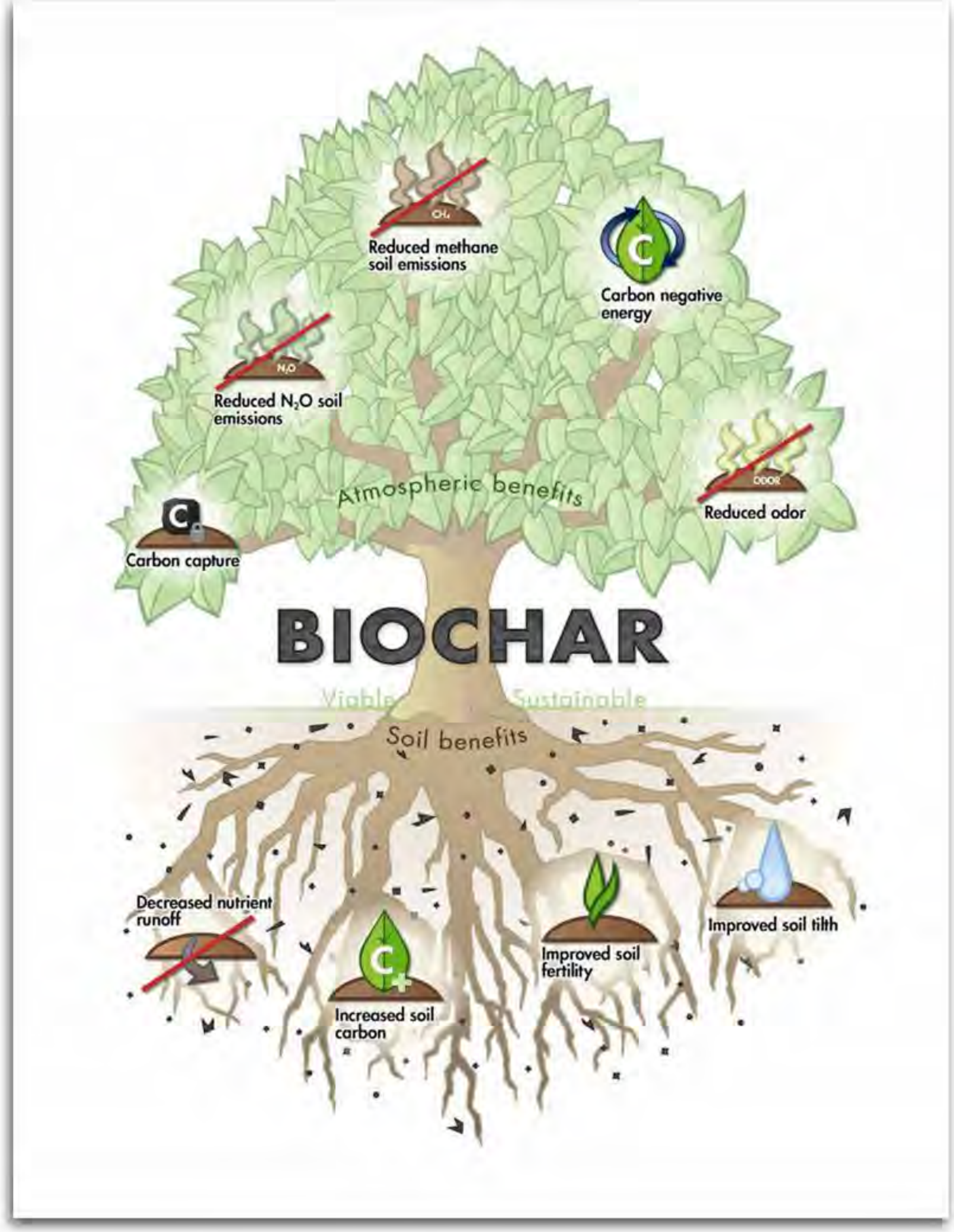

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Figure 03: Illustration showing the various benefits of biochar as a soil amendment.
Brown, Kevin, D (designer),
International Biochar Initiative Website, [sa], (Biochar).

This coincides with a key message from the FAO which states that "agricultural growth...will be most effective in reducing extreme poverty and hunger when it increases returns to labour and generates employment for the poor" (FAO 2012: 2). However, important to note is that "growth needs to result in better nutritional outcomes through enhanced opportunities for the poor to diversify their diets... [and] the poor need to use the additional income for improving the quantity and quality of their diets" (FAO 2012: 2). Thus, to contribute to the livelihood of urban agriculture may also contribute to the livelihood of marginalised communities. However, urban farming itself presents a new set of challenges to consider. One of the major challenges is that of soil quality and its resultant effect on crop productivity. Urban farmers may be affected by "poor and compacted soils with reduced water infiltration and storage capacity [as well as] loss of topsoil through erosion, erratic and highly seasonal rainfalls" (Siyakhana 2012: 1). However, conventional methods which may offer a potential solution to the poor quality of soil may "compromise the sustainability and viability of farming ventures" (Siyakhana 2012: 1).

This research study focuses on the design of a product that will produce biochar. Biochar is a carbon based substance produced by the pyrolysis of biomass, and has been proven to increase the quality of soil when used as a soil amendment (Lehemann 2012: [sp]). Certain research shows that biochar may contribute to soil quality by "retaining nutrients, decreasing soil acidity, decreas[ing] uptake of soil toxins, improving soil structure, nutrient use efficiency [and] water-holding capacity" (CSIRO 2009: 2). These functions of biochar may offer a potential means of amending poor quality soils and stimulating productivity of crops grown in this soil (CSIR 2009: 2). Thus, biochar, as a soil amendment, is an attractive avenue of exploration for urban farmers in Gauteng, and could possibly increase the viability of urban farming ventures through an increase in crop productivity. Biochar may also function as a means of waste management (Lehemann 2012: [sp]). It is estimated that invasive alien plant species (IAPs) have become established in over 10 million hectares of land in South Africa (DWAF [sa]:[sp]). A government initiative called the Working for Water programme (WfW) is currently responsible for the management of IAP eradication in South Africa (KPMG *et al* 2001: 6). The research study has identified that there is a large build-up of biomass, on previous as well as current clearance sites, managed by the WfW programme (Annexure H & K). This biomass poses a potential fire hazard and is in need of removal (Annexure H).

This research study aims to introduce biochar manufacturing technology to be used by a small business which will work in partnership with the WfW programme. The business will be established to manage the manufacture of biochar on site where IAPs are removed. The biomass from the IAP population, which is cleared by the WfW programme, will be used as a natural resource input for the manufacture of biochar.

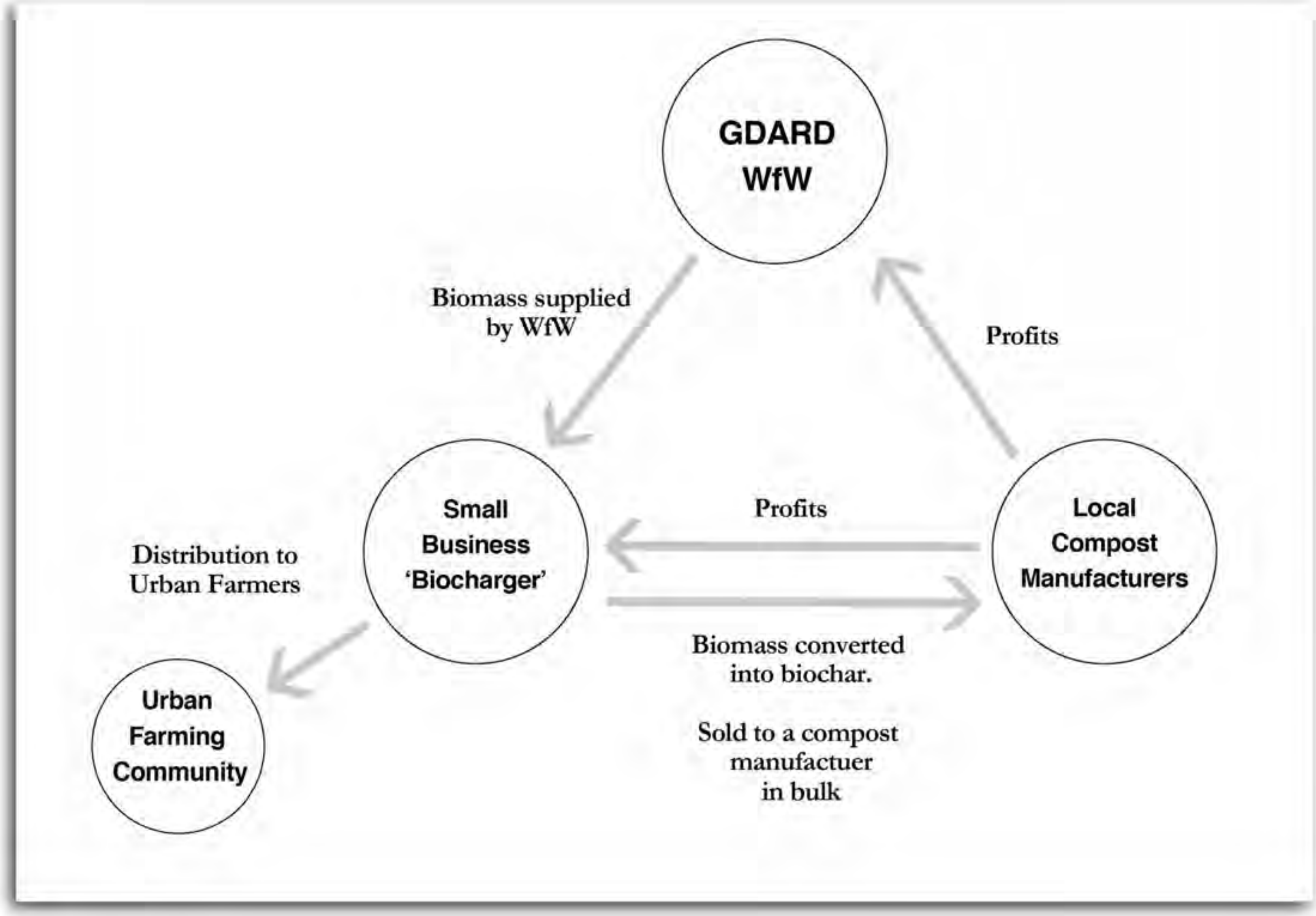

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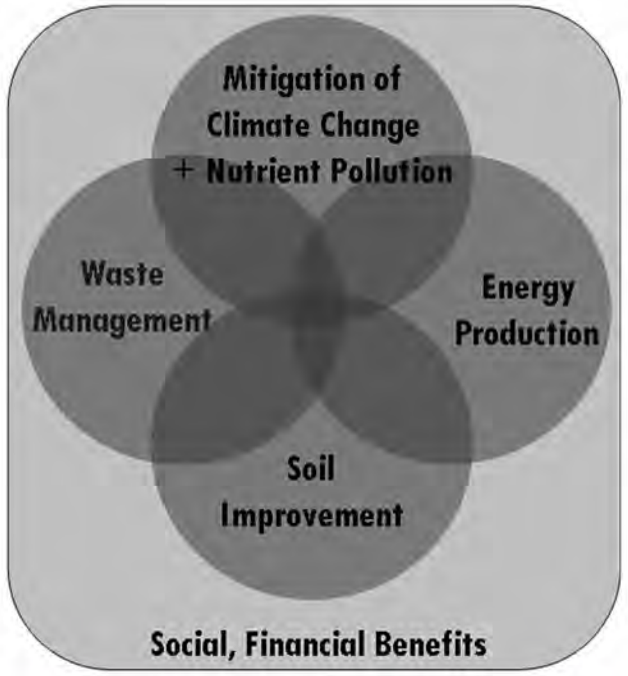
Figure 04: Diagram showing the system design for the operation of the proposed small business.
Day, Myles (designer),

The small business will offer a value proposition by removing this biomass from the land at no cost to the land owner or the WfW programme. The raw biochar will then be sold in bulk to an organic compost manufacturer who will package and sell the product. It is in the interest of the WfW programme to facilitate this business initiative as profits from the sale of the raw biochar may be used to offset the expensive costs of clearing. The management costs alone of clearing IAPs were last estimated in 2004 at R2000/ha (Marais *et al* 2004: [sp]). The small business will also make provision to supply biochar to emerging urban farmers as part of its mission to combat food insecurity by stimulating urban agriculture. The venture seeks to fulfil the primary objectives of the WFW programme which are: "minimising the net cost of clearing, maximising economic impacts, and minimising biomass to optimise environmental impacts" (KPMG *et al* 2001: 6). This study will form the industrial design research component of an inter-disciplinary project entitled: *Developing and Assessing Appropriate Biochar Technology for Emerging Urban Micro-Farmers* (Siyakhana 2012: 1). This study, and the overall project, have been initiated by *Siyakhana,* a non-governmental organisation (NGO) based at the Wits Health Consortium and the University of the Witwatersrand in Johannesburg, South Africa.

1.2. Rationale

The study is motivated by a potential solution to the issue of food insecurity in the marginalised communities of Gauteng. It is motivated primarily by evidence presented in various scientific studies which prove that biochar as a soil amendment may increase crop productivity in poor soils (CSIR 2009: 2). Therefore, if urban farmers were to use biochar as a soil amendment in poor soils, the potential that overall crop productivity would increase is very likely. As a result, biochar would offer incentives for new urban farming ventures, and increase accessibility to more nutritious food in local marginalised communities. This could help to address the growing issue of food insecurity that has been documented among marginalised communities in Gauteng (Rudolph *et al* 2008: [sp]).

The opportunity for the manufacture of biochar, to facilitate in the eradication of the IAP population in Gauteng, is also a primary motivation for the study. "Proliferation of invasive alien species can lead to serious ecological and social consequences including overuse or contamination of water, disruption of wildlife habitats, replacement of indigenous species, and impact on livelihoods dependent upon natural resources" (Legal obligations regarding invasive alien plants in South Africa [sa]:[sp]). The WfW program currently supports various initiatives that utilise the biomass of invasive alien tree populations (KPMG *et al* 2001: 15). These initiatives use the cleared biomass to make products such as "fencing and screens, furniture, home interior and décor crafts" (KPMG *et al* 2001: 15). However it is said that about 85% of the total biomass of invasive trees is unusable for such purposes (KPMG *et al* 2001: 35).



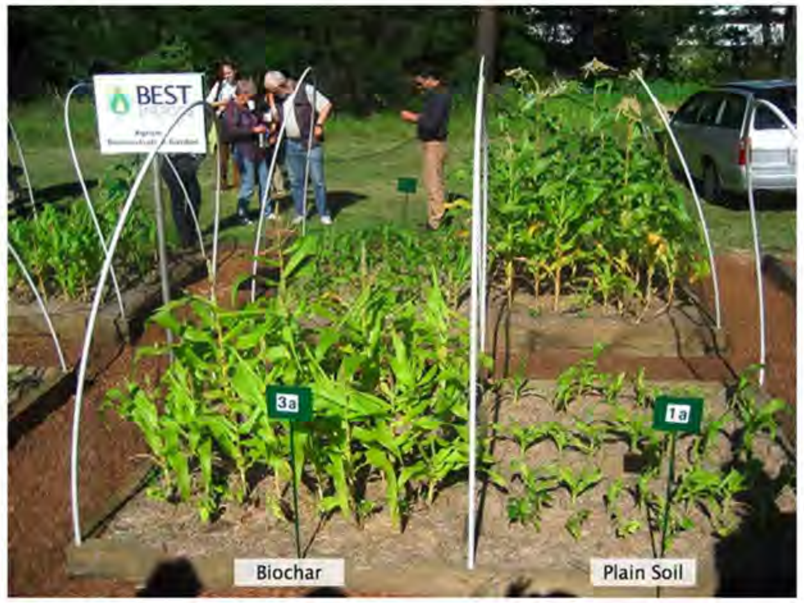


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Figure 05: Biochar System Components (Lehmann & Stephen 2009: [sa]).

Figure 06: Photographer unknown, biochar without fertiliser compared with plain soil, undated (Effects of Biochar on Soil Fertility [sa]: [sp])

Charcoal production has previously been identified as a viable means of transforming this percentage of biomass into a product which may be sold for additional income (KPMG *et al* 2001: 7). The income may be used to offset the costs of eradication which were last estimated in 2004 at R2000/Ha (Marais *et al* 2004: [sp]). However the end-use of charcoal, intended to be used as a burning fuel, is not eco-friendly and essentially contradicts the programme's development goal of "optimising environmental impact" (KPMG *et al* 2001:6). Ordinary charcoal is produced at a temperature of 400˚C (FAO 1983: [sp]), and the process by which biochar is produced reaches a temperature of about 500˚C (Mohan et al 2006: 854). There is a general consensus that this difference in temperature is responsible for imparting biochar with its unique physical and chemical characteristics, making it different to ordinary charcoal (Packard 2009: [sp]). One of the functions of biochar, as a soil amendment, is its ability to sequester carbon; this is the removal and storage of carbon from the atmosphere (Lehemann & Stephen 2009: 5). Thus the ability of biochar to contribute to climate change mitigation, through carbon sequestration, is an additional function to its use as a soil amendment, as well as the use of its production process as a waste management system (Lehemann & Stephen 2009: 5). Therefore, producing biochar from the biomass of the IAP population is a more environmentally friendly alternative as compared to charcoal intended to be used as a burning fuel.

Reasons for assigning control of biochar technology to a small business instead of introducing such technology to the small-scale farming community are as follows: A small business would support the need to "maximise economic impacts" (KPMG *et al* 2001: 6) by offering potential long term employment opportunities. Furthermore, establishing a small business means that the dissemination of biochar is not dictated by the adoption of biochar technology. Rather, it is controlled through specialised management and distribution that can be monitored and adjusted accordingly. A small business approach also eliminates the risk of urban farmers using materials not suitable to the biochar production process. In addition, the question of the farmer's ability to maintain the biochar technology, as well as whether access to raw biomass is possible, are also risk factors that are eliminated. Essentially the study is justified in its potential to:

- Improve soil quality and crop productivity by introducing biochar soil amendment to resource poor households and their farming systems.
- Improve the economic stability of resource poor households and their farming systems by stimulating productivity through the use of biochar as a soil amendment.
- Contribute to the food security of resource poor households in areas surrounding these small scale farms.
- Facilitate the eradication of the IAP population
- Create a commercialised product that may be used to offset the high costs associated with the eradication of the invasive alien tree population.
- Provide employment through a smaller business initiative to manage the manufacture and distribution of the final biochar product.

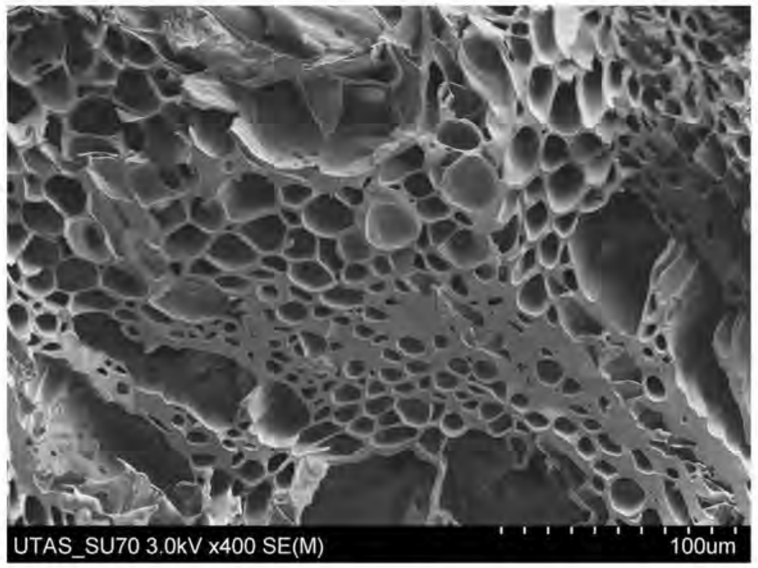
Figure 07: Harley Soltes (photographer), Clockwise from the top: biochar made from cardoon seed head, apple tree prunings, corn husks, bone, bamboo, lumber ends, rabbit droppings in center, (The Beauty of Biochar 2012: [sp]).

1.3. The Research Problem

Initially, the original proposal submitted by the NGO *Siyakhana* advocated that biochar technology be introduced directly to the urban farming community of Gauteng (Siyakhana 2012: 2). However, in a meeting between myself, the industrial design student researcher, and Siyakhana programme head Florian Kroll, a discussion, in which the logistics and financial requirements of this approach were criticised, was conducted and the need for further research into a more sustainable approach was established (Annexure C). The research methodology is based on a Participatory Technology Development (PTD) approach (Veldhuizen et al 1997: [sp]), and inspiration was drawn from previous research studies which helped identify common issues with this approach and how they might be overcome. Czech Conroy and Alistair Sutherland, in their study *Participatory Technology Development with Resource Poor Farmers: Maximising Impact through the Use of Recommendation Domains* (2004: i), offer valuable insight into PTD within the agricultural context. Conroy and Sutherland state that PTD is "resource intensive...[and] expensive...on the grounds that the high degree of heterogeneity among resource poor households and their farming systems means that the number of them adopting any particular technology will be small" (Conroy and Sutherland 2004: i). Essentially, recommendation domains are a tool used "for characterising target populations and systems" (Sutherland *et al* 2001: [sp]) and may be compared according "to a number of parameters, both biophysical and socio-economic" (Conroy & Sutherland 2004: 2).

Ultimately, the research findings in Conroy and Sutherland's study identified that recommendation domains could be used "in developing targeted dissemination strategies for specific technologies" (Conroy and Sutherland 2004: i). However the data which would have been required in "determining the size and nature" (Conroy and Sutherland 2004: 2) of a recommendation domain in the urban agricultural context of Gauteng would have proved too lengthy a process given the limited amount of time allocated to this research study. This was compounded by the fact that that even if the appropriate technology was disseminated to an appropriate recommendation domain, the source of funding for this project, currently supplied by the Gauteng Department of Agriculture and Rural Development (GDARD) (Annexure N) would prove to be an inhibiting factor over an extended period of time. Furthermore, urban farmers' access to an appropriate natural resource for biochar production, and the ability of urban farmers to afford and maintain biochar technology would also put additional strain on financial resources. It was deemed necessary to devise an approach that would become financially self-sustainable over time, the aim of which would be to reduce dependency on funding, and reduce costs for the urban farmers. Thus, the primary research question became:

"How can a biochar production unit be designed to be used by employees of a small business in Johannesburg?"



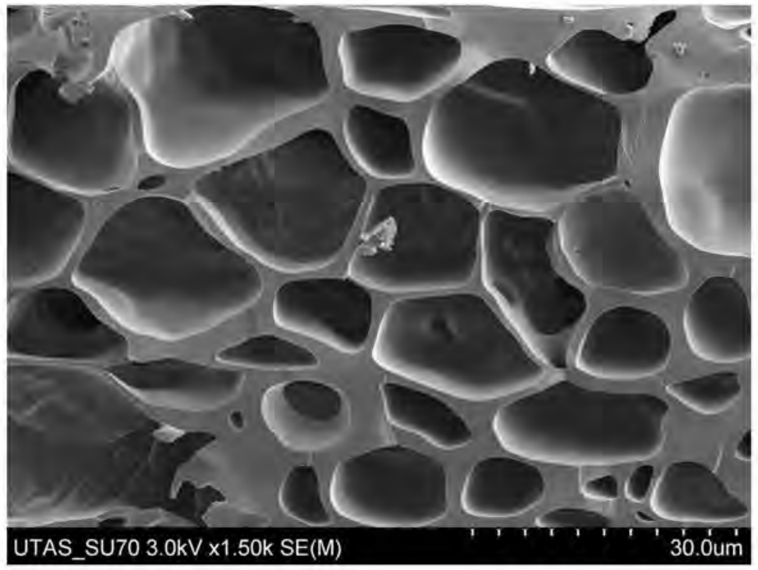


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Figure 08 & 09: Dr. Jocelyn (photographer), Electron Microscope Images of Biochar (Cooke 2011: [sp]).

The secondary research question that supports the main avenue of investigation asks:

"How can a biochar production unit be designed in order to improve access to biochar for urban-farmers in Johannesburg?"

Thus, the primary aim of the study is to design a safe and efficient biochar production unit that can be used by employees of a smaller business initiative which will work in collaboration with the WfW programme. A secondary aim of the study is to design a business plan that will effectively market the final biochar product and sustain a long term operation. The design of the unit must consider issues such as user safety and the technical requirements regarding the nature of the manufacturing process. Equally, the design should consider the user's experience of the product, particularly with regards to ergonomics and ease of use. The design may also consider aspects of the business plan such as sensitivity to capital requirements, maintenance costs, possibility of expansion, as well as marketing.

Chapter Two: Literature Review

2.1 Biochar

2.1.1. A Brief Overview

Although there is a wide body of literature relating to the topic of biochar, such literature is very particular to the discipline of agronomy and may be unfamiliar to most readers. For the sake of this document, a brief overview of the topic is required to contextualise the discussions which follow.

Biochar is the term given to biomass which has undergone pyrolysis (Figure 1), and is intended to be used as a soil amendment. The pyrolysis process (figure 2) reduces biomass to "solid, liquid, and gas by heating in the absence of oxygen" (Mohan et al 2006: 849). By introducing heat to biomass in a low oxygen environment, the biomass is essentially reduced to solid carbon. Any other constituents of the biomass are emitted as gaseous bi-products or may gather as a liquid or tar-like substance. Although the liquid and gaseous bi-products constitute a growing interest in the field of bio-fuels, this study focuses primarily on the carbon solid which is left behind. Dr. Johannes Lehemann and Stephen Joseph in their book *Biochar for Environmental Management: Science and* Technology, aptly describe why biochar is of particular interest to agronomists as well as agricultural enthusiasts.

> When Biochar is present in the soil mixture, its contribution to the physical nature of the system may be significant, influencing depth, texture, structure [and] porosity [through] changing the bulk surface area...biochar's effect on soil physical properties may then have a direct impact upon plant growth (Lehemann & Stephen 2009: [sa]).

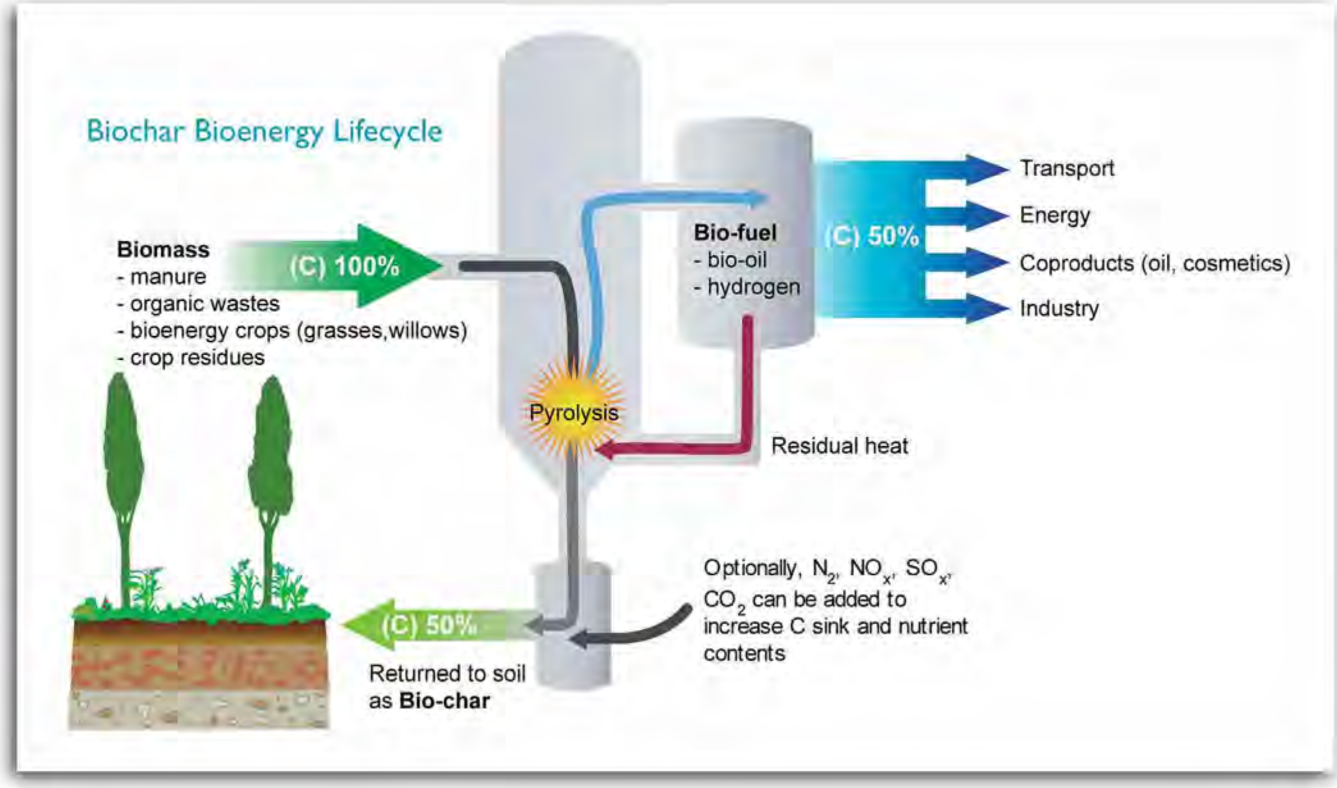

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Figure 10: Johannes Lehmann (designer), Concept diagram of low temperature pyrolysis bioenergy with biochar sequestration. (Lehmann 2007: [sp]).

According to Lehemann & Stephen, the effect of charcoal application in soils is documented in writings dating back as early as 1697 (Lehemann & Stephen 2006: 4). However, the topic of biochar has only recently received wide-spread interest, and in 2006 the term biochar was originated to label the topic of discourse (Lehemann 2012: [sa]). Lehemann and Stephen's book, which was released in 2008, can be considered as the first seminal overview in light of the relatively short lifespan of biochar. However, since 2006 there has been a dramatic increase of shorter publications in the field of biochar science (Lehemann 2012: [sa]). The *Biochar Systems Components* diagram (figure 5) represents the various spheres of application and interest associated with biochar (Lehemann 2012:[sa]). Soil improvement, waste management, and the social and financial benefits thereof have been primary motivators for the implementation of this project. However, of particular interest to this industrial design study is the production method of biochar, a topic which concerns to a large degree the disciplines of science and engineering. A key focus in this area has been the study of variables in the pyrolysis process and how these have affected the physical and chemical properties of the resultant biochar (Gaskin *et al* 2008: 2061). Literature which speaks to the engineering of the relative technology focuses primarily on the mechanics and operational procedure of precedent examples. Both disciplines are necessary to inform the context of the study, but also to inform a suitable direction. Additionally, this research study notes the profound interest in biochar among horticulturalists and hobbyists. This has been prompted by a growing body of information available through online sharing platforms such as YouTube, where a popular topic is biochar (Biochar: An Education [sa]:[sp]).

2.1.2. The Pyrolysis Process

The use of pyrolysis may be found among a variety of industrial initiatives, some of which are waste management, coke and charcoal production, and in more recent years, renewable energy and biochar (Mohan et al 2006: 848). "Pyrolysis converts organics to solid, liquid, and gas by heating in the absence of oxygen... the amounts of solid, liquid and gaseous fractions formed is dependent markedly on the process variables" (Mohan et al 2006: 849). Broadly speaking there are two types of pyrolysis: "fast pyrolysis [and] slow pyrolysis" (Mohan et al 2006: 848). Fast pyrolysis is concerned primarily with the use of vapours from the pyrolysis of biomass, however, slow pyrolysis is concerned primarily with the production of solid char (Mohan et al 2006: 854), and is the topic of focus for the purpose of this study.

A primary difference between slow pyrolysis and fast pyrolysis is the rate at which biomass is heated (Mohan et al 2006: 854). In both cases, temperatures within the low oxygen environment are regulated to facilitate the suitable pyrolysis reaction. However, the temperature of the initial heat input determines the time taken to reach this "reaction temperature" (Mohan et al 2006: 854). This reaction temperature is around 500 degrees Celsius (Mohan et al 2006: 854).

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Figure 11: Dynamotive (designer),
Dynamotive's fast pyrolysis plant in Guelph, Ontario
(Biochar Production Energy [sa]: [sp]).

Figure 12: Jason Aramburu (designer)
The Re-Char biochar kiln.
(a typical assembly which facilitates slow pyrlolysis burn)
(Burnstein 2012 : [sp]).

This high temperature is characteristic of biochar production, and differs from ordinary charcoal production which takes place at a much lower temperature (Packard 2009: [sp]). In slow pyrolysis, because biomass is heated over an extended period of time, the energy input to generate the required heat may be significantly reduced. This may be achieved by using a portion of the biomass as combustion fuel. The gradual build up of heat, to reach the optimal reaction temperature, makes slow pyrolysis accommodating of a variety of biomass shapes and sizes. Ultimately, all biomass will retain a certain level of moisture, and with exposure to heat, this moisture is evaporated and emitted as pyrolysis vapours. Slow pyrolysis vapours "do not escape as rapidly as they do in fast pyrolysis, [they have a longer] residence time...[and] continue to react with each other, as the solid char and any liquid are being formed" (Mohan et al 2006: 854). Although these vapours may still be available for capture, their present chemical composition may now be undesirable. A common method is to recycle these vapours into the combustion flame where combustible gases are consumed and make heating more efficient. The apparatus required for slow pyrolysis is far less demanding in terms of controlled variables in contrast to an apparatus which facilitates fast pyrolysis, and thus may consist of fewer components (Figure 12). However, a discussion of the relevant technology is addressed in the precedent study of this document. The precedent study also discusses other variables, such as biomass preparation and operational procedures, which are said to have a significant influence on the efficiency of the pyrolysis process.

2.2. Natural Resource Management in South Africa: The Working for Water program (WfW)

2.2.1. Overview

The topic of natural resource management in the context of South Africa is of particular relevance to this study. This section of the literature review concerns the roles of the authoritative entities in the management of the natural resource which is proposed as a primary input in the production of biochar. This section of the literature review is primarily for the purpose of contextualisation, but also to identify certain technical requirements which are relevant to the design component of this study. The WfW programme began in 1995, is an initiative of the South African Department of Water Affairs and Forestry (DWAF) and is concerned with the management of invasive alien plants (IAP's) in South Africa (figure 5). "WfW currently runs over 300 projects in all nine of South Africa's provinces [and]... works in partnership with local communities, to whom it provides jobs, and also with Government departments including the Departments of Environmental Affairs and Tourism, Agriculture, and Trade and Industry, provincial departments of agriculture, conservation and environment, research foundations and private companies" (Welcome to the Working for Water Homepage [sa]: [sp]).

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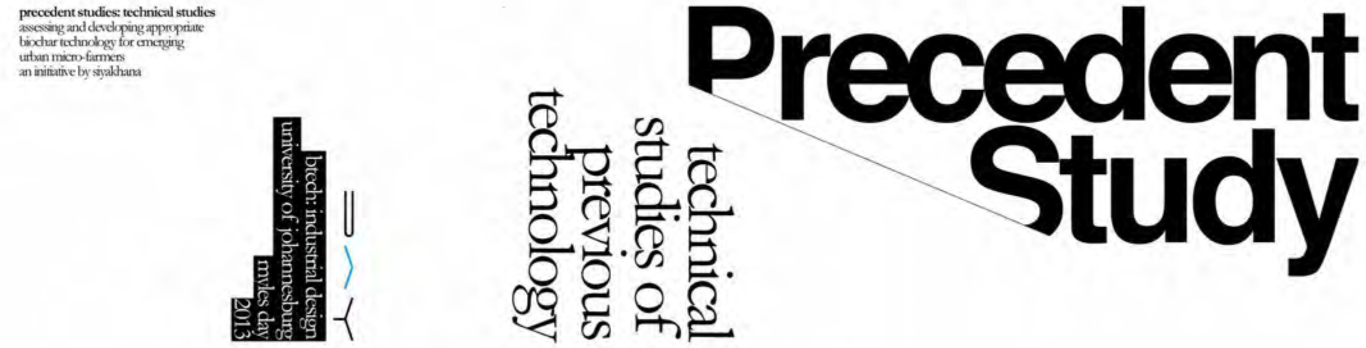
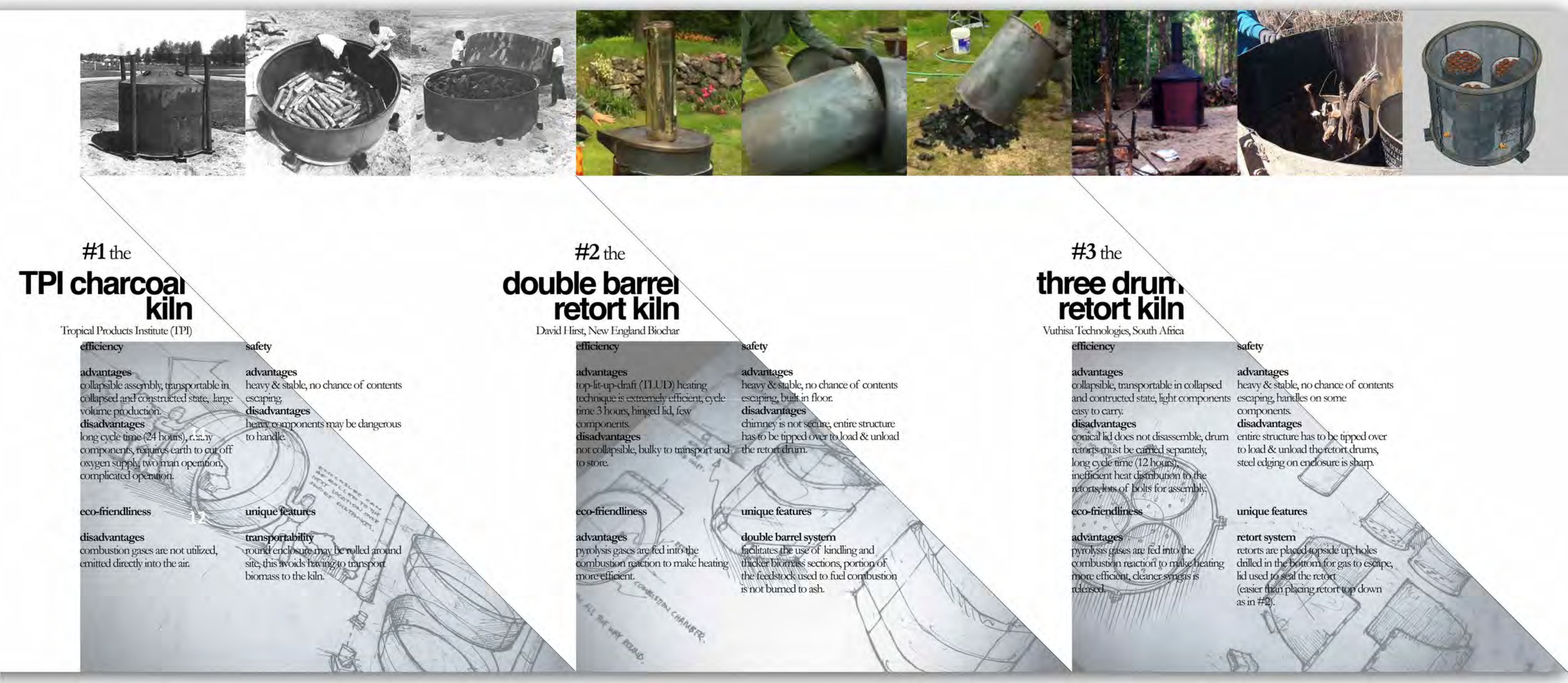
Figure 13: Myles Day (Designer), Poster displaying analyses of metal kilns selected for the precedent study, 2013.





2.1.1. Charcoal as a Potential Secondary Industry Development

A study which evaluates the development of secondary industries within the WfW programme, identifies charcoal as a viable avenue of exploration (KPMG *et al* 2001: 33). Under the analysis of charcoal as a secondary industry development, according to the environmental implications of charcoal production, it is cited that the Department of Environmental Affairs has approved the "retort system" as the only suitable means of charcoal production (KPMG *et al* 2001: 35). Essentially, "a retort is a reactor that has the ability to pyrolyze pile-wood, or wood logs over 30 centimetres long and over 18 centimetres in diameter" (Emrich 1985: 296). It is also stipulated that "only systems with such status and track record will be used" (KPMG *et al* 2001:35). As biochar production is essentially based on charcoal production technologies, it is not-coincidental that a retort system has been cited in various approaches to making biochar. Based on its environmental acceptability, it is in the interest of the study to incorporate a retort system in the design of the biochar production unit.

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Figure 14: Tropical Products Institute (designer), Transportable metal charcoal kiln, (FAO 1983 : [sp]).

2.3. Charcoal Production and Technology: Precedent Study of Metal Kilns

The following precedents were selected based on features which were deemed essential to the realisation of an appropriate design. Aspects include suitability of materials, adaptability, efficiency and sustainability, some of which are more prevalent in certain examples than others. Overall, the compendium offers a complete overview which will inform decisions in the design component of this study.

A body of literature which may be viewed as a decisive overview of charcoal production and technology is a publication by the Food and Agricultural Organisation of the United Nations (FAO), entitled: *Simple Technologies for Charcoal Making* (FAO 1983). The technical analyses regarding the engineering and operational procedures of metal kilns, is of particular interest to this study. A kiln design realised by the Tropical Products Institute (TPI) (Figure 14) is considered exemplary in terms of "economy of construction, robustness and durability, ease of operation and maximum efficiency and productivity" (FAO 1983: [sp]). To avoid lengthy explanations of production processes, technical studies of the precedents discussed in this chapter can be seen in figure 13. The technical study of the TPI kiln explains the reasoning behind certain aspects of the kiln's engineering and how they relate to the context of operation. Notably, transportability is a major design consideration of metal kilns, as this characteristic sets them apart from permanent structures such as brick kilns (FAO 1983:[sa]). Transportability is an essential design consideration in this study, as clearance projects managed by the WfW program have limited time spans in which clearance deadlines must be met (Annexure K).

15

Figure 15: Demonstration of the “Doubel Barrel Retort”.
Making Biochar: with Peter Hirst of New England Biochar, 2009
(Screenshots by Author).

16

Figure 16: Vuthisa Technologies (designer),
The Three Drum Biochar Retort
(Portable Kilns [sa]: [sp])
(Transforming the Transportable Kiln into a Three Drum
Biochar Retort [sa]: [sp]).

The technical study also considers factors which affect the yield of production. Such factors are not always directly linked to the physical design of the kiln, but rather to certain operating conditions and inputs. Thus, an analysis of the proposed context of implementation is essential to inform aspects of the physical design.

A metal kiln, used in a demonstration by *Peter Hirst*, labelled as a “double barrel retort” (figure 15), is a primary example of an efficient slow pyrolysis biochar unit, suited to small volume production (Packard 2009: [sp]). The unit promotes an eco-friendly production process and extremely efficient heating method (Packard 2009: [sp]). Moreover, because the feedstock used for combustion is not completely rendered to ash, process efficiency is additionally increased. Consideration of ergonomics was evident in various fabricated components of the design but failed to follow through to all facets of operation. This was particularly evident when the fabricated container had to be tilted on its side in order to load and unload the oil drum retort. This method could be strenuous for some users. This double barrel retort method is also dangerous as the retort is removed when the biochar is still at a high temperature. It highlights the method of loading and unloading a retort as an area which may need consideration. Furthermore, the biochar unit did not facilitate the quenching of the biochar in any way. The biochar was simply spread across the ground and hosed with water. This is a challenge as it concerns the issue of on-site water availability, and whether a designated quenching tank may be needed. Quenching is a key aspect of the production process which is often not facilitated by units suited to small and medium volume production. Quenching may require consideration in the design of the biochar unit proposed in this study.

The South African company, *Vuthisa Technologies* currently offers a product called a “Three Drum Biochar Retort” (figure 16) which is marketed as an IAP management device (Transportable Kilns [sa]: [sp]). From its immediate appearance, the design has no doubt been inspired by the TPI kiln as mentioned previously. However, it has been modified, and now accommodates three oil drums as retort containers. The Three Drum Biochar Retort is exemplary in terms of its ergonomic design and collapsible/ portable feature (figure 9). Firstly, there is no need to tilt the main housing in order to load the three oil drums. The housing can simply be arranged around the oil drums and bolted securely together. Secondly, because the main housing is a collapsible assembly, this requires less space for storage and transportation. Such collapsible assembly would be extremely useful when transporting multiple biochar units over long distances. As the apparatus consists of relatively light weight components, this also facilitates manual transportation over short distances. When assembled, the cylindrical shape of the main housing allows it to be rolled over short distances within the production site. This is seen as an invaluable feature which avoids the need to transport prepared biomass to the kiln (FAO 1983: [sa]).

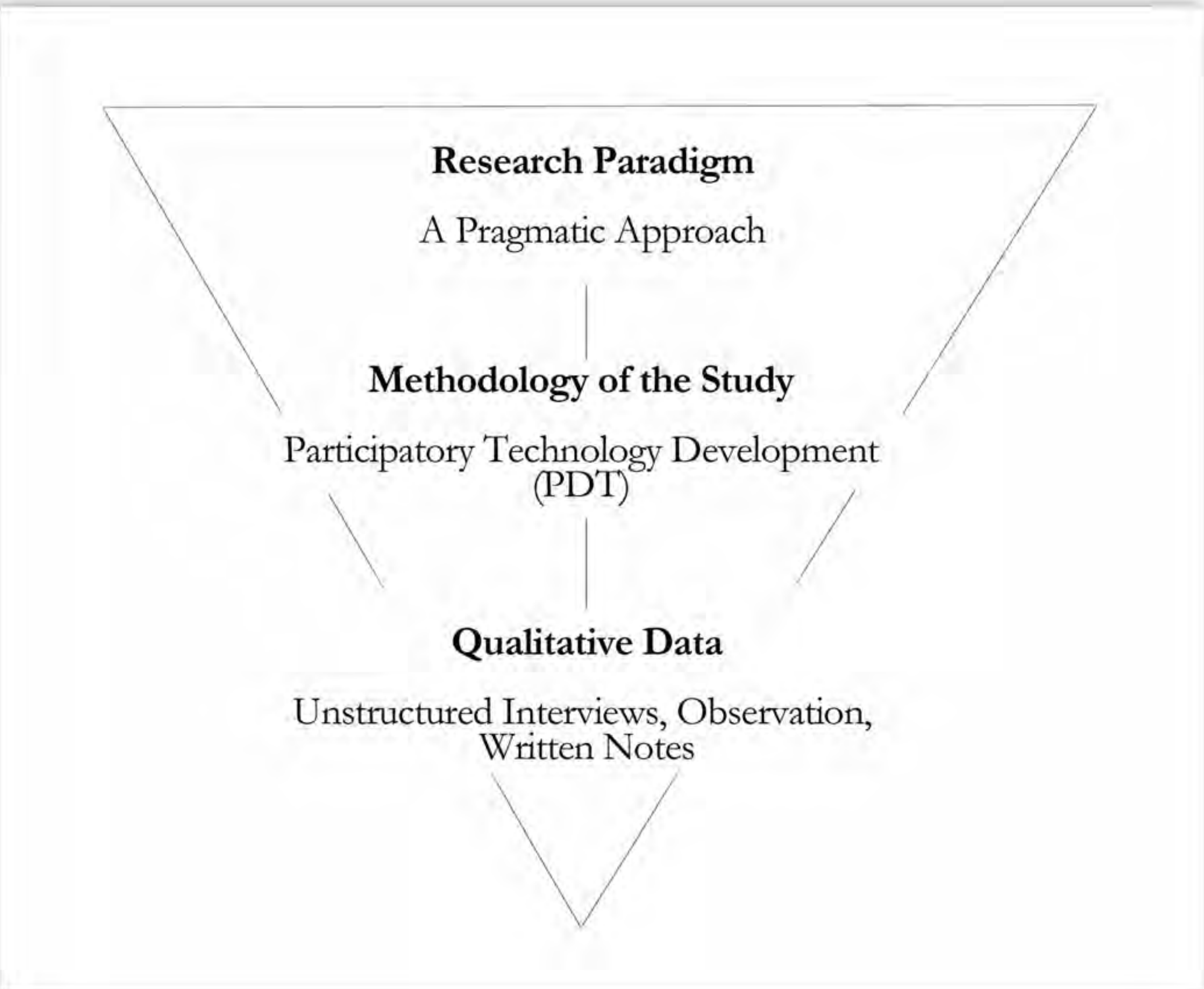

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Figure 17: Myles Day (designer), Diagram showing overview of the methodology of the study, 2013.

If the design of the biochar unit were to incorporate a collapsible feature, the packing technique of individual components to further facilitate manual transport is an important consideration. Incorporating a cost sensitive method of securing individual components, when the kiln is in and out of use, is a necessary consideration. Similarly, this unit does not facilitate the removal of the retorts from the housing container. The entire main housing has to be tilted over in order to remove the oil drums. The pros and cons of this approach, regarding this particular example, are addressed in the technical study.

Chapter 3: Methodology

3.1. Methodology of the study

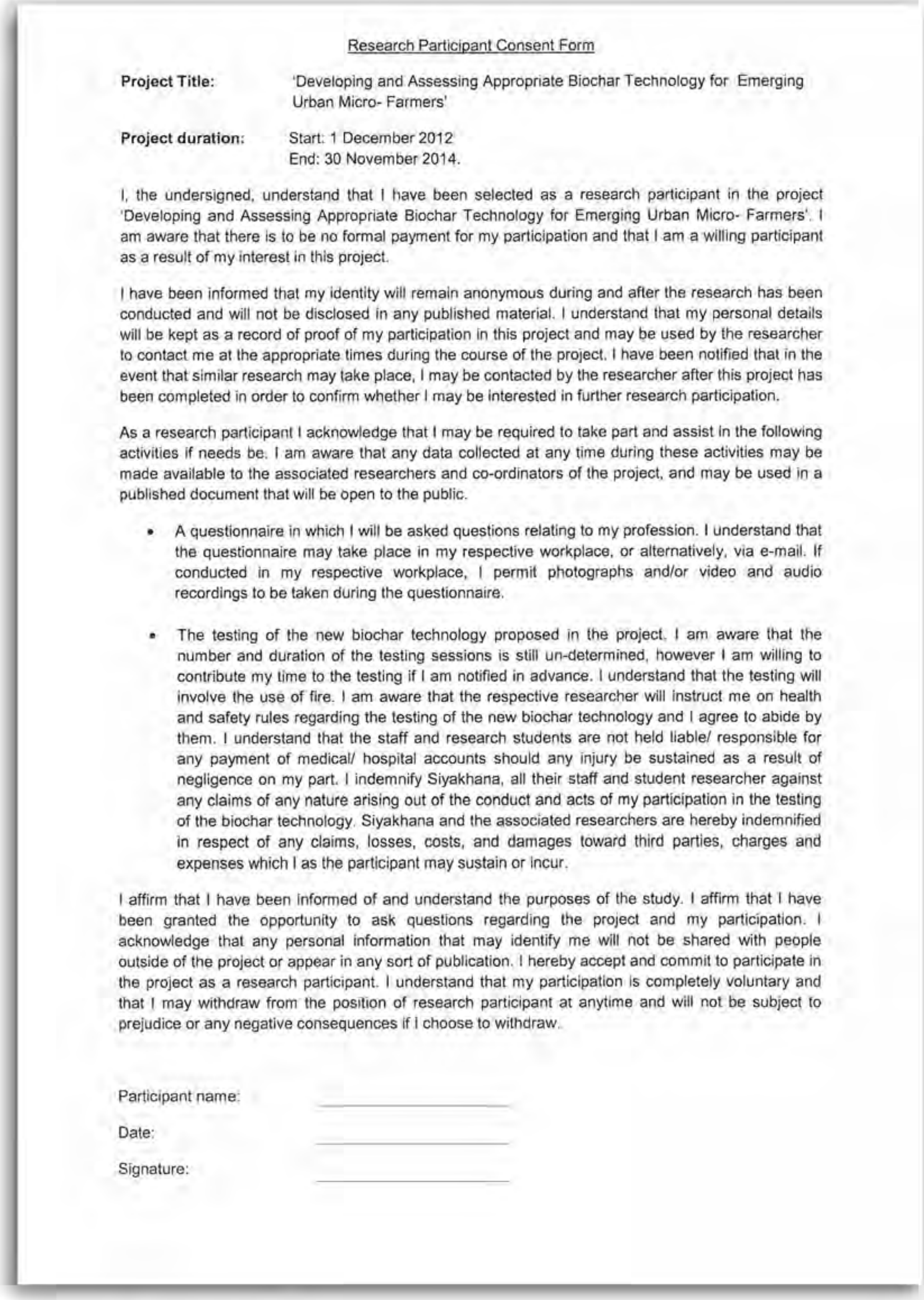
The methodology of the study was based on an approach called Participatory Technology Development (PDT) which falls under the broader category of Agricultural Research for Development (ARD) (ARC 2013:[sp]).

> PTD is a process of interaction between local people and outside facilitators to develop more sustainable farming systems. It... [includes] participatory planning, implementation, monitoring and evaluation of local development activities. The heart of PTD is experimentation with new ideas designed and conducted by farmers with the encouragement of PTD practitioners (Veldhuizen et al 1997: [sp]).

This study places more emphasis on the researcher and various stakeholders, which in this case are the originators of the "new idea" (Veldhuizen et al 1997: [sp]). According to the Agricultural research council of South Africa (ARC), PTD

> ...seek[s] to integrate the contributions of different disciplines, the perspectives and knowledge of different stakeholders, the different levels of intervention (farm, community, district, etc.), as well as balance the different outcomes of development (economic, social and agro-ecological). It recognis[es] the need to involve other actors in research, including NGOs, civil society, producer associations, the private sector, universities, etc., as well as public organisations, to respond to the challenges of innovation (ARC 2013:[sp]).

The design of the biochar production unit takes into account the contributions "of different disciplines, knowledge of different stakeholders, levels of intervention, and development outcomes" (ARC 2013:[sp]) all of which form part of a system design which considers the urban farming community of Johannesburg. This will be achieved through the introduction of a small business, and by using biochar as a common point of interest and topic of conversation to promote action towards a possible solution to the key issues addressed in this study.



Research Participant Consent Form

Project Title: 'Developing and Assessing Appropriate Biochar Technology for Emerging Urban Micro- Farmers'

Project duration: Start: 1 December 2012
End: 30 November 2014.

I, the undersigned, understand that I have been selected as a research participant in the project 'Developing and Assessing Appropriate Biochar Technology for Emerging Urban Micro- Farmers'. I am aware that there is to be no formal payment for my participation and that I am a willing participant as a result of my interest in this project.

I have been informed that my identity will remain anonymous during and after the research has been conducted and will not be disclosed in any published material. I understand that my personal details will be kept as a record of proof of my participation in this project and may be used by the researcher to contact me at the appropriate times during the course of the project. I have been notified that in the event that similar research may take place, I may be contacted by the researcher after this project has been completed in order to confirm whether I may be interested in further research participation.

As a research participant I acknowledge that I may be required to take part and assist in the following activities if needs be. I am aware that any data collected at any time during these activities may be made available to the associated researchers and co-ordinators of the project, and may be used in a published document that will be open to the public.

- A questionnaire in which I will be asked questions relating to my profession. I understand that the questionnaire may take place in my respective workplace, or alternatively, via e-mail. If conducted in my respective workplace, I permit photographs and/or video and audio recordings to be taken during the questionnaire.

- The testing of the new biochar technology proposed in the project. I am aware that the number and duration of the testing sessions is still un-determined, however I am willing to contribute my time to the testing if I am notified in advance. I understand that the testing will involve the use of fire. I am aware that the respective researcher will instruct me on health and safety rules regarding the testing of the new biochar technology and I agree to abide by them. I understand that the staff and research students are not held liable/ responsible for any payment of medical/ hospital accounts should any injury be sustained as a result of negligence on my part. I indemnify Siyakhana, all their staff and student researcher against any claims of any nature arising out of the conduct and acts of my participation in the testing of the biochar technology. Siyakhana and the associated researchers are hereby indemnified in respect of any claims, losses, costs, and damages toward third parties, charges and expenses which I as the participant may sustain or incur.

I affirm that I have been informed of and understand the purposes of the study. I affirm that I have been granted the opportunity to ask questions regarding the project and my participation. I acknowledge that any personal information that may identify me will not be shared with people outside of the project or appear in any sort of publication. I hereby accept and commit to participate in the project as a research participant. I understand that my participation is completely voluntary and that I may withdraw from the position of research participant at anytime and will not be subject to prejudice or any negative consequences if I choose to withdraw.

Participant name: ____________

Date: ____________

Signature: ____________

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Figure 18: Research participant consent form from field research at IAP site A and B, 2013 (Annexure H).

3.2. Research Paradigm

The design of the biochar production unit is influenced by data which is both qualitative as well as quantitative. This includes data from field research, the literature review, as well as the business component of the study. A journal article by Anthony Onwuegbuzie and Nancy Leech entitled *On Becoming a Pragmatic Researcher: The Importance of Combining Quantitative and Qualitative Research Methodologies* (2005) is particularly influential in directing the study towards a pragmatic research approach. This is based on the advantages of a pragmatic approach which essentially enable the researcher to "use qualitative research to inform the quantitative portion of the research...and vice versa" (Onwuegbuzie & Leech 2005: 383). This triangulation between data was the most time consuming aspect of the study and involved scenario forecasts and much correspondence with project supervisors. However, the process was extremely useful and eventually led to the realisation of a physical design and system of implementation which addresses the core issues of contextual suitability and financial sustainability. Ultimately, a pragmatic approach allowed the researcher to integrate various types of data based on interpretative and logical reasoning within the context of the study which would not have been possible by adopting a purely quantitative or qualitative research approach. Onwuegbuzie and Leech state that "pragmatic researchers have the opportunity to combine the macro and micro levels of a research issue" (2005: 383) and the range of considerations in the system design of this research study are evidence of this.

3.3. Ethics of research

Ethics of the study were primarily concerned with participant safety during the field testing of the biochar unit, informed consent of key informants during field research, and obtaining permission from the managerial authority of the WfW programme in order to conduct field research and field testing. A standardised participant consent form (figure 18) was signed by all participants (Annexure H,K,L) and established their voluntary participation and the confidentiality of their details. The consent form also established that the identity of the participant would be kept anonymous and would only be used in the documentation of the study; this included any photographs taken during the course of the research. The consent form also served as an indemnity form to participants who were involved in the field testing of the biochar production unit. Regarding ethical considerations after the field research and field testing had been conducted, there was a wide collection of data from which to choose, and it was important that the researcher selected the data which was most appropriate to the research question, and was "as clear as possible about the grounds and criteria for this selection" (Oliver 2010: 162-164).

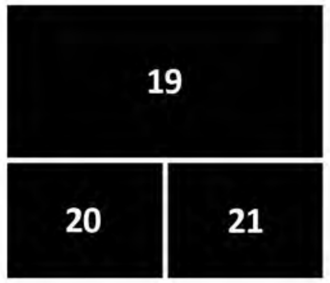

Figure 19: Panoramic shot of part of 'IAP Site A' showing clearance in progress, Pretoria, 2013
(Photograph by Author).

Figure 20: Members of 'IAP Site A' clearance team at work, Pretoria, 2013
(Photograph by Author).

Figure 21: Stack of freshly cut biomass at 'IAP Site A', Pretoria, 2013
(Photograph by Author).

3.4. Data collection methods

The initial stage of the research study consisted of two formal meetings betweenmyself, the industrial design student researcher, and Siyakhana programme head Florian Kroll. During the first meeting (26th of April 2013), various questions about the procedure of the project were raised by myself and were taken into consideration by Kroll (Annexure B). During the second meeting, myself and Kroll discussed the overall direction of the project and contact information for key informants from the Gauteng Department of Agriculture and Rural Development (GDARD) was shared by Kroll (Annexure C). Most important was the contact information for the Director of Sustainable Resource Management from GDARD, Melinda Swift. The student researcher contacted Swift via e-mail (31 July 2013) to ask for an interview and further assistance in organising a visit to a WfW clearance site (Annexure D). Swift replied via e-mail and suggested that the student researcher correspond with the three GDARD officials who had been copied in the e-mail reply. I contacted the three GDARD officials via e-mail (4 August 2013) and enquired whether it was possible to arrange a visit to the clearance sites which were under their management (Annexure E). Subsequently, two GDARD officials replied via e-mail to the student researcher confirming the possibility of a site visit.

GDARD official Muzi Mathebula replied via e-mail (19 of August 2013) confirming the possibility for a site visit to De Hoek and Vrisgewaagde in the Lesedi Municipal area (Annexure F). I acknowledged this confirmation. Mathebula provided the exact dates on which I would be able to accompany the site inspector to the clearance site, and forwarded the telephonic contact details of site inspector Antonia Bezuidenhout to organise detailed arrangements for the site visit. I contacted Bezuidenhout telephonically (19 of August 2013) to arrange the visit to the clearance site. She agreed to a site inspection and requested that I e-mail a copy of the project proposal for the purpose of contextualisation (Annexure G). Bezuidenhout confirmed the exact details for the site visit via e-mail (21 August 2013) and I attended the site inspection at sites *De Hoek* and *Uitkyk*, near the Lesedi municipal area, on the 23 August 2013 (figures 19-25). Data was collected by observation and analysis of each clearance site and by way of an unstructured interview with Bezuidenhout (Annexure H). Data was captured by hand written notes which were later summarised (Annexure H).

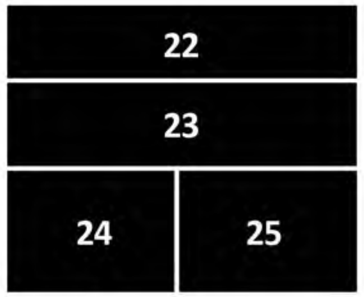

Figure 22: Panoramic shot of part of 'IAP Site B' showing expanse of invasive plant infestation, Pretoria, 2013 (Photograph by Author).

Figure 23: Panoramic shot of part of 'IAP Site B' showing the piles of waste biomass which had been accumulating for months, Pretoria, 2013 (Photograph by Author).

Figure 24: Stacks of thicker sections of biomass at 'IAP Site B' which had been left out to dry, later to be used as firewood, Pretoria, 2013 (Photograph by Author).

Figure 25: Long shot of part of 'IAP Site B' showing the larger trees on site, Pretoria, 2013 (Photograph by Author).

GDARD official Mavis Makobe replied via e-mail (26 August 2013) confirming the possibility of a site visit in Maropeng located in the Mogale City Municipal area, and in Zuurbekom located in the Wesoniaria Munipcal area (Annexure I). I acknowledged this confirmation (26 August 2013) and queried about transport availability, for the fear that their vehicle would not be suitable for the terrain in this area. Makobe replied (27 August 2013) discussing various aspects about the site visit procedure, and that both sites were accessible via tar roads. I confirmed that they would use their own transport (28 August 2013). Makobe provided me with the exact directions to the meeting place from which the team would depart to the site visit (2 September 2013) and apologized that she would not be present on the site visit due to prior engagements. Makobe forwarded the details of GDARD official Mamorakane Nkadimeng who would accompany me on the site visit. Nkadimeng contacted me (2 September 2013) to supply directions for a new meeting place (Annexure J). I attended the site inspection in Maropeng (3 September 2013) and collected data by observation and analysis of the clearance site and by way of an unstructured interview with Nkadimeng (figures 26-28) (Annexure K). Data was captured by hand written notes which were later summarised (Annexure K). The visit to the site located in Zuurbekom was cancelled as the clearance team were not present on site due to a labour strike which had occurred earlier that day.

A majority of the data regarding the engineering of the device, was informed from the precedent study. However, the field research informed the design from a contextual view point. Looking back at the technical study of the TPI kiln from the precedent study (Annexure A) it is apparent how the charcoal kiln has been adapted to suit the characteristics of the operating site of charcoal manufacture (FAO 1983: [sp]). Through this component of the precedent study, I anticipated that suitability to the proposed context of implementation would be a major influencing factor in the physical design of the biochar production unit. Therefore, observational analysis was a dominant part of each site visit and there was little that could have been prepared in terms of structured questions. Each site visit was more of an informal tour, facilitated by the site manager as they did their site inspection. However, questions were inspired by some information given by the site manager as well as by observations of the site. Thus, the tools of data collection were unstructured interviews, observational analysis, and hand written notes. A majority of each site visit was spent photographing the site and observing the terrain. Each site visit ranged from two to three hours. Intermediate questions were asked and dealt primarily with what happened to the biomass once it had been cleared. Key points were written down, and detailed notes were constructed from these main points.

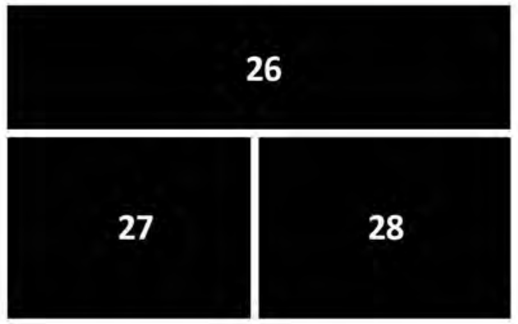

Figure 26: Panoramic shot of part of 'IAP Site C' showing the vast distance of the road along which the alien invasive trees had been cleared, Maropeng, 2013 (Photograph by Author).

Figure 27: Shot of the road estimated to be about five Km long, Maropeng, 2013 (Photograph by Author).

Figure 28: Stacks of waste biomass at 'IAP Site C' which had been left to decompose, Maropeng, 2013 (Photograph by Author).

The key points also included the various observations made around the clearance site. The use of an audio recording was omitted as questions were sporadic, and concise notes were able to be taken. These notes were then summarised, and information gathered from direct questions were sent via e-mail to each site manager for verification. The data from the site visits was then analysed with the information from the precedent study, and both were used to inform the design direction of the biochar production unit, as well as the system of implementation. The process revealed that only through visual contextualisation and observation could the required data have been gathered and the relevant points extracted. However, as the business plan progressed simultaneously to the research study, the opportunity was taken to inquire about issues which were relevant to this component of the study. Such questions were only realised in the midst of the site visit, and concerned issues such as the question of ownership of the biomass, and what happened to the biomass once it had been cleared.

The field testing of the biochar production unit took place on the De Hoek clearance site located in the Lesedi Municipal area (22 October 2013). This site was chosen because it offered flat patches of land, void of dry grass, which could be used to operate the biochar production unit. This minimizes preparation of the land before the testing could begin. The purpose of the field test was to analyse the safety, efficiency and ergonomics of the biochar production unit. This allowed the researcher to highlight areas of concern to be taken into consideration for a refined prototype. The final design of the biochar production unit required two men for its operation. Thus, the field test was a collaborative activity between the researcher and a single research participant. The research participant was previously a work colleague of the researcher and was selected on the basis of their critical thinking. The previous professional relationship with the researcher allowed for open and honest discussion which also facilitated communication about the team's experience of the unit. After the field test was completed, a focus discussion was held between the researcher and research participant to analyse the experience of the design. Findings from this portion of the research were used to inform design considerations for a refined prototype.

3.5. Design process

The design process of the research study included conceptualisation, concept refinement, prototype manufacture and initial prototype testing and evaluation. Conceptualisation involved generating a selection of concepts which considered the various findings of the field research as well as the literature review. Initial concepts were explored by use of hand sketching to communicate ideas for peer review before a direction was selected to carry forward (Annexure N). The concept refinement stage involved further development of the final direction, paying close attention to various technical aspects and finite details for manufacture. The final design was then replicated using computer aided design (CAD) software in order to prepare engineering drawings of certain components for outsourced manufacture and assembly. The final assembly was then done by me and Matthias Kroll, construction supervisor for Siyakhana.

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Figure 29: Shot of part of 'IAP Site C' showing the cluttered state of the workspace, Maropeng, 2013 (Photograph by Author).

Chapter 4: Research Findings

4.1. Field Research

In this order, clearance sites located in De Hoek, Uitkyk, and Mogale City will henceforth be termed IAP Site A, B and C. The following information regards the data which can be found in annexures H and K. IAP Sites A and B are both current clearance projects in progress AIP site C was an older site which was being revisited in order to check re-growth in the previously cleared area (figure 18). All three sites were located on privately owned land. With regards to the IAP biomass, visits to all three sites revealed that there is a large build up of biomass on site which has accumulated from the clearing process. This was a positive sign for the research study because it meant that previous clearance projects would most likely have biomass present on the land which could be used to manufacture biochar, thus contributing to utilisation of readily available resources. This biomass was stacked in arbitrary piles as the clearing process progressed . Some biomass was dragged a few meters away from the clearance area, and some biomass was stacked in the midst of the clearing area. The biomass seemed to clutter the working space, and when biomass was moved away from the clearance area, the clearing team could operate more efficiently. This was a good sign for the research study as it meant that converting the biomass into biochar could facilitate the clearing process by providing an un-cluttered working environment. The biomass was left on site even after the clearance project had been completed and as a result, the expanse of each site is littered with biomass The biomass consists mostly of the thinner parts of the tree, such as foliage and some primary branches. Larger diameter sections of the biomass are stacked separately. On each site, the clearance team is permitted access to this biomass for personal use. The larger sections of biomass are cut, left in the open to air dry, and are packaged by the clearance team to be sold as firewood. This allows members of the clearance team to generate additional income. The remaining brush line is of little use to the clearance team, and is left to decompose on site. This was not a good sign for the research study as it meant that the implementation of biochar manufacture on the WfW clearance site could impact the livelihood of the clearance team.

Seeing that the larger sections of biomass are removed by the clearance team for personal use, it means that biochar can only be made with the thinner parts of the tree. As a result, the labour intensive nature of biochar manufacture might outweigh the volume of production if the larger parts of the biomass are not available. Solutions to this problem might be to replace the biomass which is used for firewood with donations of biochar, to the clearance team, for agricultural purposes. This would require further inquiry with clearance teams under supervision of the WfW programme to ascertain whether they rely on any sort of subsistence farming, and whether they might benefit from the biochar product. In the case of AIP site A, the land owner had expressed concerns that the biomass was a potential fire hazard, and they had requested that it be removed (Annexure H).

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Figure 30: Shot of part of 'IAP Site C' showing a stack of biomass surrounded by left over tree stumps, (Photograph by Author).

This was a good sign for the research study as it meant that the removal of the biomass through the manufacture of biochar was justified on the basis of eliminating a potential fire hazard. It was expressed by both site managers that there had been little interest among small business entities for the use of the biomass. As IAP site C was an older site, there was little recollection of what had been done with the thicker sections of biomass (Mamorkane 2013). The biomass on site consisted of the thinner parts of the tree, such as branches and foliage.

The terrain of IAP sites A, B and C was accessible via motor vehicle to the main entrance by tarred roads. Once within the site any vehicle was forced to drive along a dirt road. This limited transport via motor vehicle as most of the clearing process took place away from the road. The vehicle was parked and the site inspector and myself made way on foot to inspect the clearing process. Each site consisted of a vast expanse of open land with a main dirt road for vehicle transportation. Sporadic and concentrated areas of IAP growth littered each site, with larger infestations ranged between approximately ten to fifteen hectares. In the case of IAP site C, only a selected portion of the land had been cleared as this was in obstruction of a new pipeline development by Rand Water. IAP site A and B were in the process of clearing dense areas of IAP growth, working towards complete eradication of the land. The removal process of an IAP means that the stump of the tree is left in the ground and treated with herbicide which prevents future growth. As a result, the cleared land is studded with small and larger IAP stumps which makes it difficult to travel on foot, and hazardous for any vehicle to travel over these parts of the land. This was an important consideration for the transportable aspect of the biochar production unit. The plant re-growth, prevalent on IAP site C, was the result of seed which had been spread during the clearing process. This is the result of handling the biomass whilst stacking into piles. It was revealed that even if the vegetation was burned, the flame would not destroy the seeds of the IAP. This raised concerns as to whether the temperature of the pyrolysis process facilitated by the biochar production unit would be able to destroy any seeds that would make their way in with the biomass feedstock. In order to clarify this, the biochar produced from the biomass of the IAP site would have to be tested in order to verify whether any living seeds had survived the pyrolysis process.

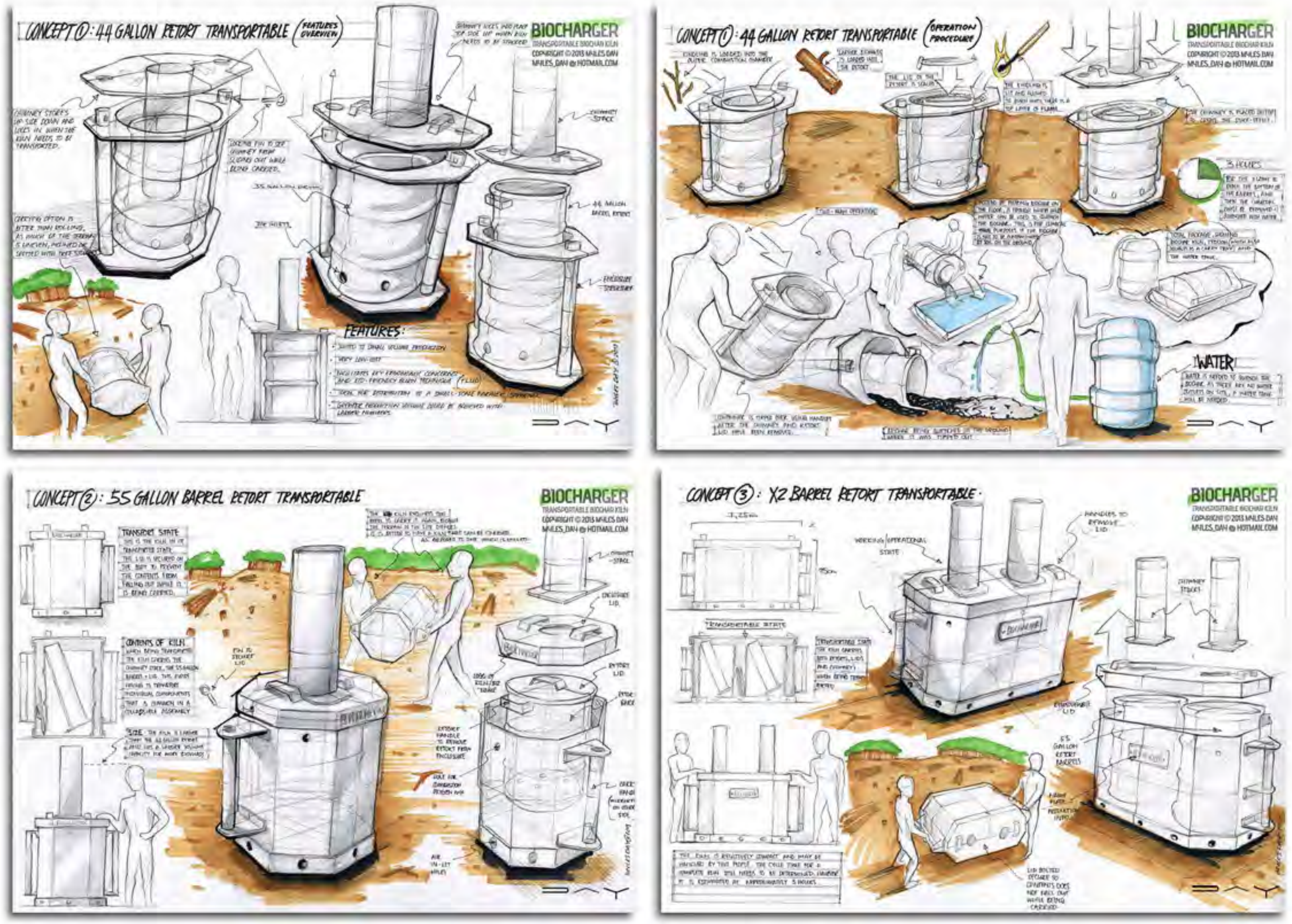

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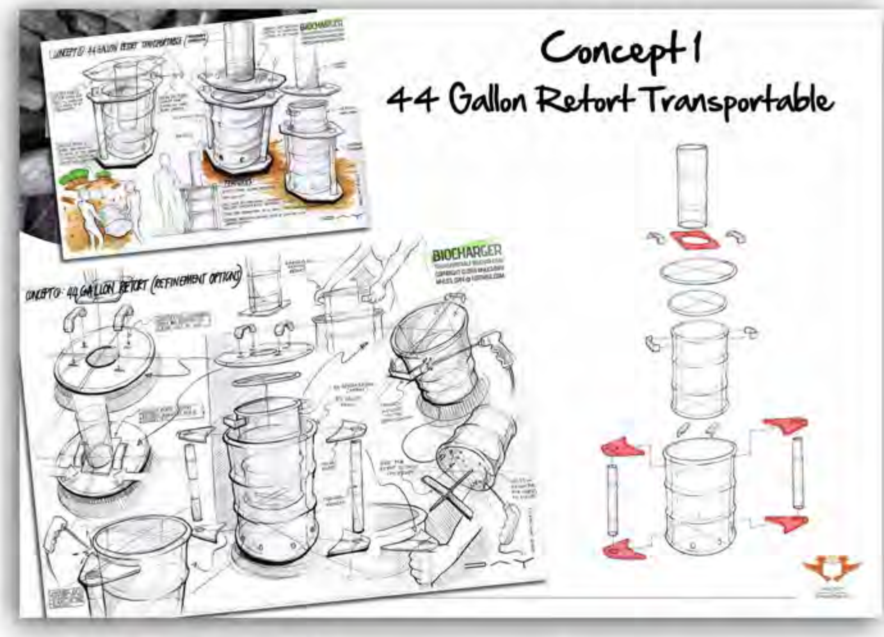
Figure 31: Myles Day (designer), group of initial concept sketches for biochar kilns,
(Photograph by Author).

Chapter 5: Product Development

5.1. Conceptualisation

The conceptualisation phase began with combining the data from the precedent study as well as the data from the field research in order to compare and extract key points of consideration for the design of the biochar kiln. It was immediately apparent that the kiln would have to be manually transported over land by physically carrying the kiln. Incorporating a wheel system into the design was abandoned as this mode of transport would be problematic as the terrain of the clearance sight is typically studded with tree stumps, tall grass, rocks and waste biomass. As identified in the precedent study, the enclosure of the *Three Drum Biochar Retort* by *Vuthisa Technologies* can be rolled around sight to reduce the amount of physical labour required to transport the kiln. However, this approach only solved half the problem as the rest of the components would have to be physically carried anyway. Also, as was observed from visit to IAP site C (Annexure K), parts of the site had a relatively steep gradient which could prove hazardous if the kiln operator were to lose control of the rolling object. Thus, the designer sought to incorporate all the components of the kiln into a single packed unit when the kiln was out of use, the aim of which was to make transporting the kiln more convenient, as well as limiting the amount of storage space needed for the unit. All of the units were based on the operating principles of the *Double Barrel Retort* kiln (Packard 2009: [sp]) as this kiln had the most efficient cycle time. Having an efficient cycle time was deemed crucial to the operation of a small business which would be confined to a seven hour working day.

The conceptualisation phase saw the origination of three concepts each of which embraced the aforementioned transportable characteristic. However, each kiln concept offered a range of choice between cost and biomass feedstock capacity. Concept one focused primarily on reduced cost by dramatically reducing the amount of outsourced manufactured components and relying primarily on readily available materials which only required minor adjustment and assembly. Concept two, essentially an up-scaled version of concept one, offered a larger loading capacity and relied more heavily on outsourced manufactured components as well as some readiliy available components. Concept three focused on pushing the boundaries of the loading capacity of the concept and also relied on a mixture of outsourced manufactured components.



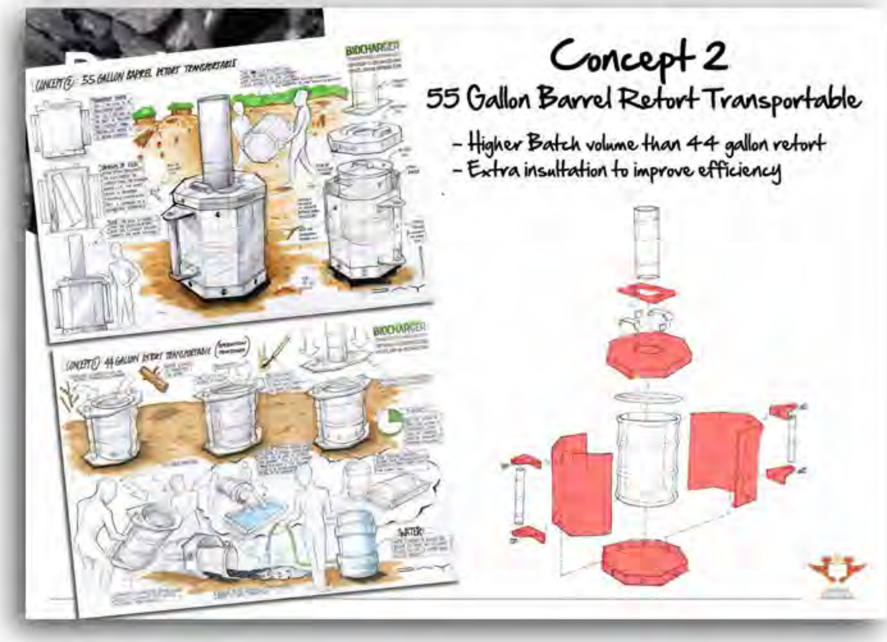


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Figure 32: Myles Day (designer), refinement sketches for kiln concept one (Photograph by Author).

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Figure 33: Myles Day (designer), refinement sketches for kiln concept two (Photograph by Author).

5.2. Concept Refinement

Initially, it was decided that the study would pursue kiln concept three based on the aim of maximising volume output per single unit. However, by using CAD software to conduct a mass properties analysis, it was found that the estimated weight for this concept (150Kg) would be far too heavy for a manually transportable kiln. Thereafter, it was decided that both kiln concepts one and two would be refined and produced. The aim of producing both of these kilns was to field test both prototypes and compare the efficiency and production outputs in relation to the cost of each unit. This would allow the study to verify the more viable option. The operating principles of the *Double Barrel Retort* kiln on which each concept was based is facilitated by a phenomena known as "the stack effect" (Packard 2009: [sp]). In the context of the design of the kiln, this phenomenon is responsible for the flow of air through the kiln as well as the removal of gases through the chimney component. Seeing that kiln concept one and two were similar in size to the *Double Barrel Retort* kiln, the dimensions of the chimney and other features such as air in lets were based on the information provided in this example (Packard 2009: [sp]).

The researcher sought to reduce the amount of out sourced manufactured parts in concept one even further. The final design required only five small laser-cut steel components. The rest of the assembly consisted of sections of readily available steel tube and steel flat bar, a few nuts and bolts and a 210 litre and 100 litre oil drum. The final design for kiln concept two consisted of eleven laser-cut components of varying sizes, sections of readily available steel tube and steel flat bar, a few nuts and bolts, and a 210 litre oil drum. Certain components were repeated in the assembly of both kilns to reduce the number of different components, and parts were also optimised to use the most of standard lengths of material made available by the supplier. As certain components would be exposed to higher temperatures than others, in both instances a bolt-together assembly was favoured as it would allow parts to be removed from each other in the case that one component had reached the end of its lifespan before another. It was decided that each kiln would not receive any kind of protective finishing as this would increase costs, and have a high risk of being destroyed by the heat produced by the kiln. Instead, each kiln would be fitted with a steel plaque, etched with the product identity, manufacturing information, and a space for the user to record the number of runs the kiln had been completed as well as the number of times it had been repaired. It was decided that experimentation with low cost, manual finish applications could be tested as the kilns were subject to further test runs to evaluate their life spans.

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Figure 34: Myles Day (designer), logo designs for the biochar kiln showing progression to final design, 2013.

5.3. Product and Business Identity

The name given to the small business was *'Biocharger'*. The name is *an* obvious insinuation to the biochar substance. However the name retains an emotive quality which alludes to a hardened attitude and intense activity which reflects the nature of the business. The name was deemed appropriate for the business as well as the kiln which could be specified by a model name or number. *The* tag-line 'Transportable Biochar Kilns' identifies the area of expertise and service offered by the business. A logo and colour scheme were designed for the company to facilitate with company and product identity recognition as well as marketing of the company through various applications such as vehicle vynls, business cards, and a promotional brochure and DVD.

Chapter 6: Field Testing of Biochar Kilns

6.1. Initial Field Test

The initial field test of the biochar kiln was carried out on the 22nd of October 2013, on IAP Site B, which is located in Lesedi, Gauteng, South Africa. The field test was organised via email with GDARD official Antonia Bezuidenhout (Annexure P). GDARD officials, Antonia Bezuidenhout and Mduduzi Ndlovu, accompanied me and professional photographer Paul Samuels to the site where the biochar kiln was tested. Both kiln prototypes derived from concept one and concept two were transported on a bakkie to the sight. The process began by clearing a patch of land on which the kiln would be tested, removing any grass, biomass and other obstructions. Wood to be used as a feedstock for the kilns was then prepared, and consisted of biomass derived from the Poplar tree species. Members of the clearance team were kind enough to cut larger sections of biomass with their chainsaws as these sections of biomass could not be prepared by hand. Thinner sections of biomass were gathered by myself, Bezuidenhout and Ndlovu from the stacks of biomass on site. This biomass was broken down into smaller pieces by machetes and by hand. The process of preparing the biomass took approximately two and a half hours and would have been significantly longer if members of the clearance team had not assisted with the processing of the larger biomass sections. The larger kiln derived from concept one, was packed with the biomass first so that biomass could be processed for the smaller kiln whilst the larger kiln had been lit. The outer combustion chamber of the larger kiln was packed with a mixture of biomass, sections with a 5mm diameter to sections with a 30mm diameter were used. Sections were placed at random into the combustion chamber, until the feedstock reached the tip of the retort drum. The retort drum of the larger kiln was packed with biomass sections with diameters ranging from 50mm -70mm. Once the kiln had been packed with biomass, the lid of the retort was replaced and sealed using a steel ring-top seal, a standard component of the ring-top drum (Figures 35-40).

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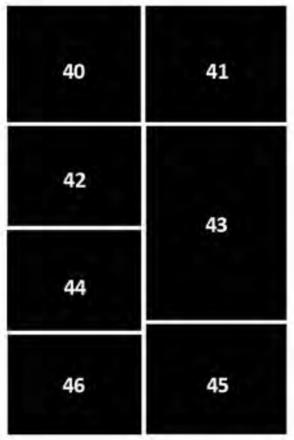
Figures 35- 40: Paul Samuels (photographer), images showing procedure of packing and lighting the large kiln, Dehoek, 2013.

The purpose of the ring-top seal is to keep the lid of the retort in place, and prevent oxygen from entering the pyrolysis environment in the retort drum. The top layer of feedstock in the outer combustion layer of the kiln was then packed with newspaper. Glycerol, a flammable waste product derived from cooking oil, was poured over the newspaper, which was then lit using a lighter. The fire was allowed to burn for about 30 seconds, and then the lid of the kiln was replaced, and the chimney stack was placed on the lid. The kiln was kept under constant observation during the burning process. Observations that were noted at the beginning stages of the burn were:

- The kiln released a lot of smoke from the chimney outlet.
- The wood in the combustion chamber located closest to the combustion in-let hole, burned much faster than the wood on the opposite side of the kiln.
- Parts of the kiln located near the primary inlets warped from the heat generated by the combustion of oxygen.

The kiln had been burning for about an hour, when the land owner arrived to where the kiln was being tested. The land owner demanded that the burn process be stopped as they were extremely concerned that it was a potential fire hazard. I had not contacted the land owner personally, but was under the impression that permission for the field test had been organised by Bezuidenhout as per my request via email (Annexure P). Bezuidenhout asked the land owner whether her supervisor, Mathebula, had spoken to them prior to the field test. The land owner stated that they had not received any notification from anyone. The land owner maintained her demand that the kiln be shut-down, and promptly left the site where the kiln was being tested. Myself, Bezuidenhout and Ndlovu collected water from a nearby source using a 100 litre container that had been brought on the field test for this purpose. The water was mixed with soil to create mud, which was then used to block the primary oxygen in-lets of the kiln. The chimney stack was then shut using the lid of the retort from the smaller kiln. The kiln was allowed to subside for approximately 30 minutes. After this time, when the flames of the fire had died, the chimney and lid of the kiln were removed, as well as the lid of the retort, and the contents of the combustion chamber and the retort were quenched with water. Once the contents had been significantly quenched, the kiln was tipped onto one side, and the contents were spread onto the cleared area where it was further quenched with water. Myself and Bezuidenhout then went to the land owner to apologize in person for the miscommunication. As a result, the small kiln was not tested.



Figures 40- 45: Matthias Kroll (photographer), images showing procedure of packing and lighting the large kiln for second field test, Linbro Park, 2013.

7.1. Secondary Field Test

A secondary field test was held on the premises of Mathias Kroll, in Linbro park, Sandhurst, Gauteng South Africa. Matthias Kroll had assisted with the assembly of the kiln prototypes and kindly agreed to assist with the testing of the kilns on his premises. The procedure for the testing of the large kiln was changed slightly, based on aspects of the procedure of the initial field test which may have contributed to the inefficient burning of the kiln. Using spare steel from the assembly of the kiln, steel handles were welded onto the chimney stack (figure 40). This addition allowed easier handling of the chimney stack, and also prevented the operator from having to touch the surface of the chimney while it was still hot. A make-shift air-stopper was also used to block the combustion in-let hole (figure 41). This was made in such a way that it could be adjusted and removed during the burn. Matthias Kroll had an abundance of wood available on the premises to be used in the second kiln test. This wood was derived from Black Wattle trees growing on the premesis, which had been cut during routine maintenance. This wood had been stacked and left to air-dry over time. The wood was reduced into smaller pieces using an axe and chopping block, which took approximately three hours. The diameter of sections of this wood ranged from 5mm – 70mm. The thicker sections of this particular type of wood were extremely hard, and very difficult to chop manually. Thinner sections were easily broken into smaller pieces by hand. The packing method of the combustion chamber and the retort drum were also approached differently. The wood which had been collected was graded according to thickness, namely small, medium and large. A combination of these sections was used to pack the combustion chamber of the larger kiln. Wood was also stacked vertically to assist with the airflow through the kiln enclosure. Wood with small and medium sections was used to fill the gaps between wood with larger sections. Using a long wooden pole, the wood in the combustion chamber was compacted intermittently to minimise the air spaces in the combustion chamber. This process of packing and compacting the feedstock, aimed to provide sufficient feedstock to maximise the resident time of the burn. This would ensure that the contents of the retort would be completely pyrolysed. The retort was packed with a mix of different woods, of all shapes and sizes, ranging from small to relatively large. Packing the retort in this manner aimed to establish whether there was a limit to the size of the wood that could be pyrolysed. The retort was only packed to about two thirds of its capacity due to a lack of wood, and lack of time to harvest more. The lid of the retort was replaced, and forced down with a rubber mallet. The steel ring component of the drum was placed around the lid of the retort, and the securing bolt was tightened using the appropriate spanner.

The top layer of wood in the combustion chamber was packed with paper from and old telephone book (figure 45). The paper was packed so that each piece of paper would touch the next, this would allow the flame from one to transfer to the other. Thinner parts of wood were replaced over the

Figures 46- 48: Matthias Kroll (photographer), images showing large kiln burning efficiently, gases being combusted in the top section of the kiln, producing a flame out of the chimney and a smokeless burn, Linbro Park, 2013.

paper, and the same Glycerol substance from the initial field test was poured over the paper and top layer of wooden twigs. The paper was then lit an various points using a lighter. The flames were allowed to burn for approximately a minute, and then the lid of the kiln was replaced, and the chimney was stacked on top of the lid. The kiln immediately began producing an excessive amount of smoke, which was released from the chimney. Using bricks to cover the primary air in-lets at the base of the kiln various combinations of closing and opening the primary air-inlets, as well as the combustion inlet were experimented with. The kiln had burned for approximately two hours, and had released an excessive amount of smoke, which was the opposite of what was intended. The kiln was meant to cycle the gases released from the retort into the combustion chamber, where they would then be consumed, resulting in a smokeless burn. Similar to the initial field test, the wood on the side with the combustion in-let was burning at a much faster rate than the wood on the opposite side of the kiln. Matthias Kroll identified that the one combustion inlet was not providing enough oxygen at the top of the kiln for the flame to combust the gases released from the retort drum. In order to provide more oxygen at the top of the kiln, extra holes were drilled into the opposite wall of the kiln, in an effort to equalize the oxygen distribution. This did not make any difference, and the chimney continued to smoke. In another attempt to provide more oxygen to the top of the kiln, the chimney stack and lid were removed, and Matthias Kroll placed two angle-iron beams across the opening of the kiln. The kiln lid and the chimney stack were replaced, and the kiln seemed to produce less smoke. I identified that perhaps the angle iron cross bars were allowing too much oxygen into the system, and that we should try something thinner to support the lid on. Spare steel flat-bar from the assembly of the prototype were placed across the opening of the kiln, and the lid and chimney were replaced in the same way.

The modification yielded the desired result, and gases from the retort were now being combusted at the top of the kiln enclosure. A small amount of smoke was still being released from the chimney, and so the primary air inlets were closed using bricks. Matthias Kroll identified that, if this configuration had been used from the beginning, the primary inlets could possibily be closed very early into the burn cycle. The kiln then began to burn efficiently, producing only a hot clean flame from the chimney, instead of a smoking burn. The prototype had achieved one of its primary goals, which was to burn efficiently and sustainably. One major flaw that was noted was that the primary air-inlets and wall joints had allowed embers from the combustion chamber to escape. This would be a major fire hazard in windy conditions. The kiln continued to burn efficiently for another two hours. Due to time constraints, the lid and chimney were removed after this time, and the contents of the kiln and the retort were quenched with water. The contents of the retort had been completely pyrolysed, except for a few sections of wood closer to the bottom of the retort.

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Figures 49- 50: Photographs of samples of larger sections of biomass which had been pyrolysed into biochar and retrieved from the retort of the large kiln, 2013, (photograph by Author).

Complete pyrolysis of the wood in the retort could have been achieved if the kiln had been allowed to burn to completion. Various samples of the biochar from the retort were photographed to illustrate the ability of the kiln the pyrolyse a variety of woods. Although the contents of the retort had been quenched, after leaving the biochar in the retort over night, the residual heat had caused the biochar to burn to ash. This prompted the need for a permanent water source, such as a water trough or barrel, in which biochar could be placed, eliminating the chance of the residual heat rendering it to ash. Due to time constraints the smaller kiln was not tested.

Chapter 7: Conclusion

7.1. Closing Statements

7.1.1. Summary of the Outcome

This study has attempted to design a system whereby the production of biochar may be used to create a sustainable and possibly profitable business venture, which could facilitate dissemination of the biochar product to the target community. The assumption has been that the profitability of such a venture hinges on eliminating transport of the biomass to a central manufacturing location. However as the findings reveal that on-site manufacture of biochar may be too risky, such a business venture would have to adapt the infrastructure of its operation to ensure that on-site manufacture of biochar is 100% safe. Alternatively, the business venture could opt for a centralised location of biochar manufacture in exchange for being only self-sustainable whilst fulfilling a social need.

The most important lesson that has been learned is that testing of a product which involves the use of fire should only ever be done in controlled conditions, and with expert supervision. This has brought into question the safety aspect of producing biochar on-site where the environment may be extremely vulnerable to fire. Unless the kiln is guaranteed to contain the combustion of the kiln, the idea of a small business producing biochar on-site, where there is an abundance of biomass, is out of the question. Even if the kiln is proven to be 100% contained and safe, the risk of fire escaping is too great to be justified by the benefits of removing the biomass from the land. The consequences that the government department, land owner, and small business would face if a fire were to run loose could be very serious. This is an aspect of the study which has not been identified by any supervisors, even with interim presentations that relayed the process of the operations plan, and the intention of field testing on-site. It has been the most important realisation of the study.

With regards to the design of the kiln, it has been noted that preparation of the biomass is an extremely time consuming task, and that some sort of mechanised method of processing the wood would make the process more efficient. It was also noted that a finely processed feedstock, such as woodchip, would be more ideal for the outer combustion chamber. This is based on the assumption that a greater density would create a longer residence time, and thus ensure the complete pyrolysis of the retort feedstock.

This is also based on the assumption that the higher density would facilitate a more constant burn-line, than a mix of different sized biomass sections. The kiln design could be modified to extract and distil wood gas to be used to run the motor of a wood chipper, based on gasification principles. The excess heat of the kiln could also be utilized more efficiently by using it to dry wood chips. To make the kiln safer, and reduce the chance of fire escaping, the primary in-lets should be modified with a channel that would prevent embers from the combustion chamber from escaping. An inner sleeve, made of corrugated steel, placed in the combustion chamber between the wall of the kiln and the feedstock, could also be used to prevent embers escaping from the primary inlets. This sleeve would also facilitate more efficient mixing of oxygen along the height of the kiln, if perforations were made along part of its vertical length. The primary inlets could be relocated in a position where there would be sufficient material to prevent warping from the heat generated by the combustion of oxygen. All inlets could receive adjustable hole coverings to control the inlet of oxygen, and shut-off the oxygen supply if necessary. Ultimately the kiln needs to be modified and tested under a variety of conditions in order to determine its actual safety and efficiency. This study has been successful in establishing that the kiln can burn efficiently. However extensive testing in conditions which simulate the proposed environment of production, and which also incorporate the various changes to the apparatus, would be needed to establish the safety of the unit.

With regards to the operations plan proposed for the business component of the study. To avoid the risks associated with producing on site, biomass could be transported to a semi-permanent location off-site. This would increase costs of the operation and jeopardize the chance of the venture being financially profitable. However, if the goal of the business were simply to be sustainable whilst fulfilling a social need, this approach may still be viable. If production were to happen on-site, a sufficient supply of water should be readily available in the case that any fire does escape from the kiln. Another option may be that the kiln is operated in a larger enclosed area, such as a shipping container. This would provide a safe place for operation of the kiln, as well as storage against bad weather conditions, and prevent theft of the equipment. A larger container may also provide a means of transport on a larger scale, and provide a structure which may facilitate drying of the biomass to be used in the production process. Whether such a business could ever be incorporated into the mandate of the WfW programme, as a service which removes the biomass form the land, is highly doubtful. This is based on the assumption that many land owners may find the risk of such an on-site operation too high.

7.1.2. Recommendations for further study

One of the governing aspects of this study has been the need to design a financially sustainable system using biochar technology. The potential of batch production units to facilitate an operation large enough to sustain a system of this nature, can only be determined through further testing, and evaluation of prototypes.

This study has focused on establishing that biochar can be made sustainably with a batch production unit, and has explored how to maximise the efficiency of the manufacturing process, as well as the safety of the operation of the device. However, the study has not explored the full utilisation of the bi-products of the manufacturing process besides biochar, namely heat energy, and gaseous energy. The technology may be adapted to utilise these bi-products to maximise the efficiency of the system design by addressing separate components of the production cycle. In another context, the way in which all of the elements of the manufacturing process are used, may be dictated by the findings of an individual researcher, and their identification of the needs of specific communities. The multi-faceted nature of the manufacturing process, and the multiple potential uses and functions of the bi-products of the manufacturing process make biochar technology a potential avenue of investigation in cases where energy is gained from fire.

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FIGURES SOURCE LIST

FIGURE 1:

FIGURE 2:

FIGURE 3: Biochar. [sa]. [O]. Available: http://www.biochar-international.org/
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FIGURE 4: Diagram showing the system design for the operation of the proposed small business, Myles Day (Designer).

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FIGURE 8 & 9: Cooke, D. 2011. Electron Microscope Images of Biochar Hi Res. [O]. Available:
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Figure 13: Myles Day (designer), poster displaying technical analyses of metal kilns selected for the precedent study, 2013.

FIGURE 14: Food and Agricultural Organization of the United Nations (FAO). 1983. *Simple Technologies for Charcoal Making.* Rome: FAO

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FIGURE 17: Myles Day (designer), Diagram showing overview of the methodology of the study, 2013.