Masters by Coursework Project
Final Project Report
2018: A Humanitarian Approach to Biochar

Author: Nishanth Cheruvu
Student ID: A1607236
Date: 03/03/2016
Project No.: 2018
Supervisor: Dr Cristian Birzer

School of Mechanical Engineering
The University of Adelaide

2018: A Humanitarian Approach to Biochar
# Masters By Coursework Project

## 1.1 To be Completed by the Principal Supervisor

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<tr>
<th>Student’s Name</th>
<th>Nishanth Cheruvu</th>
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<td>Title of Project</td>
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- ☒ I am satisfied with the content and technical presentation of the student’s report and consider it to be of an acceptable standard for examination in its current form.
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Cristian Birzer

03/06/2016

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1.3

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Executive Summary

“Biochar may represent the single most important initiative for humanity’s environmental future. The biochar approach provides a uniquely powerful solution, for it allows us to address food security, the fuel crisis, and the climate problem, and all in an immensely practical manner.” Prof. Tim Flannery 2007 Australian of the Year (Flannery, 2008)

Biochar is created when charcoal is produced from the heating of biomass in the absence of oxygen. Biochar has recently been found to be beneficial to soil amendment, due to its ability to improve soil fertility and increase the capacity of the soil to store carbon dioxide, referred to as soil carbon sequestration. The ability of biochar to aid carbon sequestration is characterised by its stable nature, which allows biochar to stay in the soil for what some suggest could be as long as five thousand years (Hossain et al., 2011). The burning of trees and organic matter is a major contribution to the amount of carbon dioxide released into the atmosphere. The use of biochar in soil will allow for a significant reduction in greenhouse gas levels in the atmosphere, as the carbon dioxide can be stored in the soil. Subsequently, the carbon sequestration can aid in improving the quality of the soil, which would in turn boost agricultural productivity. Biochar has the potential to become a fundamental part of sustainable development in poor communities; tacking issues such as food insecurity, poor productivity, and biodiversity loss. The by-products created by the production of biochar include syngas and bio-oil; two products that can be used as alternatives to the comparatively inefficient wood fires. The reduction in the associated greenhouse gas emissions and the avoided deforestation, as well as the health benefits from reducing the exposure to indoor air pollution make biochar a viable option in the alleviation of agricultural, physical, and economic hardships.

This is a report outlining the progress made by Project 2018: A Humanitarian Approach to Biochar. The project will investigate the characteristics present – and required – in biochar to generate the most effective solution while minimising any negative impact. The three aims of the project are detailed below.

1. Multiple samples of biochar will be produced using a variety of production methods, equipment, and feedstock, which allows for a varied analysis.
2. Research will be conducted into the characteristics of biochar produced using the various samples. Characteristics including surface area, pH, absorption and any other relevant aspects to be determined during the research phase of the project will be analysed and compared. An analysis of these characteristics will reflect how well the biochar can mimic activated carbon, which enhances plant growth.
3. Comparisons to existing biochar production methods and uses will be made in order to find methods that both generates the most effective characteristics, while minimising any deficiencies from a humanitarian aspect such as resources, cost, and environmental impact.

The Australian Qualifications Framework (AQF) Level 9 requirement states that this Masters Project must satisfy the following condition:

“Research comprises systematic experimental and theoretical work, application and/or development that results in an increase in the dimensions of knowledge.”

Research currently exists on how biochar is created but there exists very little research on the impact on biochar characteristics with respect to differing production methods and biomass sources that also consider the negative environmental and economic impact of the biochar. Finding an improved production method that generates the most effective biochar while minimising any negative environmental impact will increase the efficiency of current agricultural practices, while simultaneously encouraging the use of alternative fuel sources such as biomass. Research into the methods, which will be furthered through testing, qualitative and quantitative analysis, and comparison of the results meets the AQF Level 9 requirement for this Masters by Coursework project. The following deliverables will be used to detail the progress, results, and analyses of the project:

1. Project Proposal
2. Project Definition Statement and Plan
3. Mid Project Report
4. Seminar
5. Final Report
Each deliverable will consist of the development of a draft, followed by amendments and editing prior to the final submission. Any amendments to the project deliverables will involve input from both the supervisor and the student. This document contains a detailed outline of the project objectives, with a thorough schedule outlining significant milestones, deadlines, and project phases. This document will also contain a project management plan that encompasses project requirements and outcomes. A detailed project plan containing a work breakdown structure, and a Gantt chart outlining the projected schedule have also been derived. The resources required to complete the outcomes of this project, as well as the risks involved, have also been discussed in this report.
# TABLE OF CONTENTS

CERTIFICATION OF REPORT FOR EXAMINATION .................................................................. 3
MASTERS BY COURSEWORK PROJECT .............................................................................. 3
ACKNOWLEDGEMENTS ...................................................................................................... 5
EXECUTIVE SUMMARY ..................................................................................................... 6

1 DEFINITIONS AND ACRONYMS .................................................................................. 10
  1.1 DEFINITIONS ........................................................................................................... 10
  1.2 ACRONYMS ............................................................................................................. 10

2 INTRODUCTION AND BACKGROUND ........................................................................... 11

3 LITERATURE REVIEW .................................................................................................... 13
  3.1 INTRODUCTION ....................................................................................................... 13
  3.2 BIOCHAR .................................................................................................................. 13
    3.2.1 HISTORY ......................................................................................................... 13
    3.2.2 APPLICATIONS ............................................................................................... 13
    3.2.3 BY-PRODUCTS ................................................................................................. 14
  3.3 PRODUCTION METHODS .......................................................................................... 15
    3.3.1 Slow Pyrolysis ................................................................................................. 15
    3.3.2 Fast Pyrolysis ................................................................................................. 15
  3.4 CHARACTERISTICS .................................................................................................. 16
  3.5 SUMMARY AND RESEARCH GAPS ......................................................................... 17

4 AIMS AND PROJECT OBJECTIVES .............................................................................. 18
  4.1 PROJECT CONSTRAINTS: ......................................................................................... 19

5 PROJECT MANAGEMENT ............................................................................................... 20
  5.1 PROJECT REQUIREMENTS ...................................................................................... 20
  5.2 PROJECT OUTCOMES ............................................................................................. 20
  5.3 JUSTIFICATION PROJECT ADDRESSES RESEARCH BASED REQUIREMENT .......... 21
  5.4 RISK ANALYSIS ..................................................................................................... 21
  5.5 MONITORING MECHANISMS .................................................................................. 25

6 EXPERIMENTS .............................................................................................................. 26
  6.1 INTRODUCTION ....................................................................................................... 26
  6.2 PRODUCTION .......................................................................................................... 26
    A.1.1 Equipment ....................................................................................................... 26
    A.1.2 Feedstock ........................................................................................................ 31
  6.3 TESTING .................................................................................................................. 33
    A.1.3 Yield ................................................................................................................ 33
    A.1.4 By-products ..................................................................................................... 33
    A.1.5 Absorption ....................................................................................................... 33
    A.1.6 C/H/N Analysis ............................................................................................... 33
    A.1.7 pH ................................................................................................................... 33

7 RESULTS ...................................................................................................................... 34
  7.1 INTRODUCTION ....................................................................................................... 34
  7.2 BIOCHAR SAMPLES ................................................................................................. 34
1 Definitions and Acronyms

1.1 Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
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<tbody>
<tr>
<td>Biochar</td>
<td>Charcoal stored in soil as a means of removing CO₂</td>
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<tr>
<td>Bio-oil</td>
<td>Synthetic fuel extracted by the biochar production process</td>
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<tr>
<td>Carbon Sequestration</td>
<td>A process by which CO₂ is removed from the atmosphere</td>
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<tr>
<td>Catalytic</td>
<td>Involving the action of a catalyst (substance that increases rate of reaction without itself being affected)</td>
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<tr>
<td>Gasification</td>
<td>Process that converts fuels into CO, H, and CO₂</td>
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<tr>
<td>Macroporous</td>
<td>Structure with cavities larger than 75 micrometres</td>
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<tr>
<td>Pyrolysis</td>
<td>Decomposition by high temperatures</td>
</tr>
<tr>
<td>Syngas</td>
<td>Fuel gas mixture generated by biochar production process</td>
</tr>
<tr>
<td>Terra Preta</td>
<td>Dark fertile man made soil found in the Amazon Basin</td>
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1.2 Acronyms

<table>
<thead>
<tr>
<th>Acronym</th>
<th>Definition</th>
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<tr>
<td>AQF</td>
<td>Australian Qualifications Framework</td>
</tr>
<tr>
<td>ASTM</td>
<td>American Standards for Testing and Measurement</td>
</tr>
<tr>
<td>C/N</td>
<td>Carbon to Nitrogen ratio</td>
</tr>
<tr>
<td>CHN</td>
<td>Carbon Hydrogen Nitrogen</td>
</tr>
<tr>
<td>SMART</td>
<td>Specific, Measurable, Assignable, Realistic, Time Related</td>
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<tr>
<td>UNICEF</td>
<td>United Nations Children’s Fund</td>
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<td>USDA</td>
<td>United States Department of Agriculture</td>
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2 Introduction and Background

An increase in population and consumption growth over the next 40 years will result in an increase in the global demand for food (World Bank, 2008). Resources such as water, energy, and agriculturally viable land are found in the midst of growing competition; this, along with overfishing of the oceans, and a need to curb the environmental impact of the food system, will affect the ability to produce food in the future (Charles et al., 2010). The currently growing global population is expected to plateau at approximately nine billion by 2050, which correlates with an increase in the consumption of food, subsequently increasing the demand placed on the food supply system (UN, 2004). The cumulative effect of these issues, along with a need to mitigate the threat of climate change creates a need to produce the food more efficiently. The term ‘food security’ initially referred to whether a country had access to food that could meet its dietary requirements. A country was said to have national food security if it produced the food needed to meet population demands. A more modern interpretation states that food security exists when “all people, at all times, have physical and economic access to sufficient safe and nutritious food to meet their dietary needs” (Pinstrup-Andersen and Pandya-Lorch, 1998). A study by the United States Department of Agriculture (USDA) has indicated that the number of food insecure people in the world exceeds two billion (Meade and Rosen, 2013). One of the most promising solutions to make food production sustainable while managing greenhouse gas emissions is through the use of biochar, specifically the ability of biochar to sequester carbon in soil. Carbon sequestration in soil involves the transference of atmospheric carbon dioxide into the soil, where it is stored securely and not immediately remitted. The most effective method of carbon sequestration is through the use of biochar, credited with causing minimal soil disturbance, improving water retention in the soil, enhancing soil structure, and increasing the biodiversity of the soil. The use of biochar to sequester organic carbon in the ground also has the potential to restore degraded soils and ecosystems. In locations with high levels of soil degradation such as South Asia, Africa, and the acidic savannas of South America, the depletion of organic carbon in the soil has adversely affected the soil productivity and placed a high priority need for soil restoration. Achieving food security through soil amendment is a critical point of improvement that can be achieved by the ability of biochar to sequester organic carbon in the soil.

Countries with the highest incidence of food security in most parts of the developing world, also have a high incidence of poor energy usage, and the associated indoor air pollution effects (Socioeconomic Data and Applications Center, 2005). There are currently over 3 billion people in the world who rely on the burning of solid fuels such as wood, dung, and crop residue to meet their energy use requirements (WHO, 2014). Economic and social factors are the main restriction preventing access to improved fuels for these people, most of whom live in developing countries in Africa and Asia; areas also affected by food insecurity (Meade and Rosen, 2013). The burning of solid fuels releases emissions such as carbon monoxide, carbon dioxide, and nitrous oxides. When this occurs indoors, it is a source of significant levels of indoor air pollution, and has health effects that result in the death of approximately 2 million people yearly (UNICEF, 2012). Issues such as respiratory infections, pulmonary diseases, and lung cancer all increase as a direct result of smoke inhalation and indoor air pollution (WHO, 2014). As well as the health issues associated with the burning of solid fuels, there are significant environmental aspects that occur as a result. These include climate change caused by the release of greenhouse gases during the process of burning solid fuels, and deforestation caused by the need to source the solid fuels. It is estimated that the burning of solid fuels is responsible for approximately 18% of global greenhouse gas emissions (Bond and Sun, 2005). Wood is the major source of solid fuel use and accounts for 90% of the total solid fuel use in rural communities (Foell et al., 2011). The use of wood for energy purposes has resulted in significant levels of deforestation all around the world (McGranahan 1991). These issues make it important to find a modern alternative to solid fuel use, such as bio-oil and syngas.

Bio-oil and syngas are two by-products created when biomass is turned into biochar through a pyrolysis process. Bio-oil is generated as a result of the fast pyrolysis process and is a mixture of water and organic compounds. Currently, bio-oil can be used as a replacement for heavy oil in commercial boilers and some steam turbines, and as a replacement for petroleum in asphalt production. Synthetic gas, also known as syngas, is a primary product of the gasification process and is primarily used as an alternative to methane, or natural gas. Syngas can be burned directly, used in gas engines, or even converted to clean diesel fuel.

The issues of food security, the fuel crisis, and the climate and health problems that arise as a consequence of solid fuel use and indoor air pollution require a simple and effective solution that can be implemented in rural communities globally, in order to improve quality of life. Biochar provides a unique solution as it can be effectively used to either amend or counteract all the aforementioned problems in one way or another. One of the ways that the issue of food security can be resolved is through better, more productive use of the available resources in order to maximise food producing capabilities. The use of biochar as a vessel for carbon sequestration in soil holds many benefits such as improving water retention, increasing the capacity for nutrient absorption and retention, and generally aiding the soil structure to improve the agricultural performance of the land and increase crop yields in areas where the growing medium for staple foods might be damaged or deteriorated. Carbon sequestration also performs the crucial task of removing atmospheric carbon dioxide
from the environment and storing it in the soil, thus reducing overall greenhouse gas emissions. Using biochar as a tool for soil amendment also allows for greater yield of crops and trees, which helps counteract deforestation, consequently counteracting greenhouse gas emissions. The use of biochar to mitigate the fuel crisis has an interconnected threefold advantage:

- **Health issues** – The use of biofuels generated as by-products during the biochar production process allows for a cleaner alternative to solid fuel use which results in indoor air pollution. The negative health issues as a result of solid fuel burning, smoke inhalation, and indoor air pollution can be avoided through the use of alternative fuels such as bio-oil and syngas.

- **Carbon sequestration** – In order to obtain the biofuels, biochar must be generated. The generated biochar can then be put to use by placing it in the soil which removes carbon dioxide from the atmosphere and reduces greenhouse gas emissions.

- **Biofuel** – The use of generated biofuels, such as bio-oil and syngas, as alternatives to solid fuel use help reduce the reliance on wood fuel in most of the global rural population. This has a direct effect environmentally, as it helps reduce deforestation by eliminating the demand for a wood fuel source.

Most of the existing research and studies into the effectiveness, characteristics, and use of biochar have taken a specific, local approach. These studies focus on researching the effect of biochar on either specific soil types, or local crop yields. Listed below are three such studies that although detailed and well done, focus on either certain soil types or certain growing conditions:

1. Temperature and duration-dependent rice straw-derived biochar: Characteristics and its effects on soil properties of an Ultisol in Southern China (Peng et al., 2011)
2. Effects of biochar from slow pyrolysis of paper mill waste on agronomic performance and soil fertility (Van Zweiten et al., 2009)
3. Biochar addition to agricultural soil increased CH4 uptake and water holding capacity – Results from a short-term pilot field study (Karhu et al., 2011)

This emphasis on producing ‘designer biochar’ leaves a lot of scope for biochar to be investigated and compared in a general overview, by comparing the characteristics exhibited by various types of biochar. The aforementioned reports focussed on specific points relevant only to their local conditions; whether it involves the use of paper mill waste as a biomass, or conducting studies specific to South China or Finland.

The first objective of this project demonstrates an ability to produce biochar using the most basic of equipment and feedstock, and will allow for a general analysis of the similarities and differences between multiple samples. The results and analysis from the project will hopefully provide a general overview comparing the effectiveness of biochar with respect to its characteristics, such as yield, surface area, and absorption. Other characteristics such as the capability of the biochar to retain nutrients, and the pH neutralising effects of the biochar will be tested as well. This will hopefully result in a clear analysis of the biochar characteristics that can be used to find the ideal ‘type’ of biochar needed to maximise productivity and efficiency, based only on the needs posed by the agricultural situation. The third and final objective of the project states a need to investigate the biochar production methods, feedstock, and uses from a humanitarian perspective in order to find a method that both generates the most effective biochar while minimising any negative aspects.

This project will aim to analyse, compare, and suggest improvements to biochar in such a way as to find an ‘ideal’ biochar that takes into account any relevant constraints and negative aspects. No single type of biochar will be the answer to soil amendment and carbon sequestration issues all over the world, so the aims of this project will be to rate the effectiveness of biochar as dependent on its individual characteristics. This will help allow the final results of this project to be used in a way that investigates the most effective biochar in any situation, as opposed to the best ‘designer biochar’ for a specific purpose.
3 Literature Review

3.1 Introduction

This section contains a review of the existing literature and knowledge in the field of biochar research. The literature review in this section will cover a few basics about biochar; its history, applications, and by products. The production methods used to produce biochar will also be briefly investigated. Finally, key characteristics of biochar, and the advantages and disadvantages they pose towards determining the effectiveness of a biochar sample will also be reviewed.

3.2 BIOCHAR

3.2.1 HISTORY

Although the term ‘biochar’ was coined as recently as 2005 (Smolker, 2015), the concept originated centuries ago in pre-Columbian Amazon. ‘Terra Preta’ or Black Earth was used to describe the fertile, black soil found in large patches all over the Amazon River basin (IUCN, 2012). These large patches were found to be in areas of historic habitation, with sites of up to 350 hectares in area reported (Smith et al. 2009). Analysis of the soil composition in the early twentieth century found that the land was rich in mineral residue, decomposed organic material, and charred plants. The effectiveness of biochar was known to ancient Amazonian civilisations; and consequently fascinated even modern soil scientists. Chemical fertilisers could not maintain continuous crop yields over three growing seasons, but terra preta had facilitated a fertile growing environment for centuries. In areas where the soil is acidic, the use of biochar in the soil was shown to increase the productivity of the terra preta soil by increasing nutrient retention and maintaining a neutral pH. Early research showed that a crop planted in the terra preta soil produced a fourfold increase in yield as compared to a crop planted in similar soil without biochar characteristics (Glaser et al., 2001).

The source of the fertility in the soil was found to be carbon, with early research showing that terra preta soil contained up to 9% carbon content – compared to 0.5% carbon content in the surrounding soil (Sparks, 2010). The carbon content is also considered to be the source of the dark colour of the soil. Incompletely combusted organic material from household fires and field burning is considered to be the source of char in the soil, deliberately cultivated as a way to manage low fertility levels in the soil. Consequently, terra preta also displayed higher levels of nitrogen, potassium, and calcium. Similar patches of char-enriched soil have been found in Ecuador, West Africa, and South Africa, as well as other countries (Lehmann et al., 2006). Research suggests that the practice of biochar use in soil to manage low fertility has been implemented globally in a historical context.

3.2.2 APPLICATIONS

Biochar has recently been popularised as a mechanism to reduce the effects of climate change. As biochar is rich in carbon, and has the ability to retain that carbon, it is considered a useful tool to aid carbon sequestration. Biochar is also capable of repairing soil with its ability to retain water and nutrients. Therefore, biochar provides benefits to the agricultural sector as well as aiding with environmental issues such as deforestation. This preliminary literature review will cover two of the basic applications of biochar: its impact on crop productivity; and its role as a carbon sink. A more detailed review of the applications of biochar will be presented in the critical literature review.

3.2.2.1 Crop Productivity

Both history and research have shown that Biochar provides a number of benefits when used for soil amendment. Many of the benefits of biochar appear to be related to the porous structure of biochar, which is extremely effective at retaining water, and water soluble nutrients. Field trials have been run since 1980, experimenting with the use of biochar types on specific soils. Early studies conducted during the 1980s and 1990s were reviewed by Glaser et al., (2001), and showed high impact on soil quality when added in small quantities (0.5 tonnes per hectare). But at higher rates, the addition of charcoal was shown to inhibit crop growth. Other studies have been conducted since then (Asai, 2009; Blackwell, 2007; Rondon, 2007) that have assessed crop yield of staple grains in terms of their short-term response to biochar application.

The main source of feedstock for these studies has been commercially produced charcoal from wood, to simulate conditions under forest wildfires. Two additional studies have used poultry litter (Chan, 2008) and organic crop waste (Chan, 2007). These studies have tested a range of moderate rates of addition of charcoal (5-15 tonnes per hectare), with some of the studies testing the rate of addition as a variable, ranging from high (60-300 tonnes per hectare) to very high (small scale experiments conducted in pots). The charcoal used in these experiments were generally alkaline, and produced at a low temperature range (340°C – 450°C). The charcoal was added to tropical soils with an acidic pH level, and experiments – in all the studies – were conducted for a mean duration of less than eight months.

A review of these experiments showed that biochar addition resulted in positive yield effects for most of the tests. Improved soil function, fertiliser use efficiency, higher crop yields in soil containing nitrogen, phosphorous, and potassium, and higher
crop yields in semi-arid soil pot trials were all reported in a review of the experiments. Repeatability of these results in terms of consistency and predictability are needed in terms of framing biochar for use in large-scale applications to generate higher yields and greater financial profit (Sparks, 2010). As scientific repeatability of testing biochar is lacking, a review of these experiments showed that finding the role that specific characteristics play in influencing the effectiveness of biochar is useful.

The ability of soil to retain water is influenced by the amount of minerals and organic content in the soil. Soil containing higher levels of organic components was found to have a greater water holding capacity, although this capacity was shown to be temporary unless managed. Terra preta was found to have an 18% increase in water retention compared to surrounding areas as a consequence of both higher biochar content in the soil, as well as increased levels of organic matter that appear to be associated with the presence of charcoal. Research has shown that biochar is stable in soil and can provide a long term amendment option to the water holding capacity due to its macroporous nature, which has a direct impact on soil texture at a macroscopic level. Modification of the physical structure of the soil, which is one of the effects of biochar, results in chemical stabilisation of nutrients, increase in water holding capacity, and an increase in the ability of the soil to retain nutrients.

3.2.2.2 Carbon sink

The ability of biochar to act as a mechanism for long term carbon sequestration has driven the interest in the technology as a feasible way to mitigate climate change at a global level (Lal 2009). Recent estimates of the effect of greenhouse gases have shown that the atmospheric concentration of carbon dioxide is at 379 ppm, and is increasing at rate in excess of 1.8 ppm per year (IPCC, 2007). The effect of deforestation on the earth’s natural resources are pronounced as well, with a land area of approximately 7.1 million hectares per year being destroyed. Woolf et al. (2010) found that carbon sequestration, with the use of biochar, has the potential to reduce the quantity of greenhouse gas emissions in the atmosphere by up to 12%. Life cycle analysis of biochar systems have been conducted by Roberts et al. (2010) have found that the source material used as well as the ability of the biochar to produce biofuel by-products affect the biochar ability to mitigate climate change. As biochar can be produced through the pyrolysis of any biomass, and as the effectiveness of the biochar is dependent on the characteristics imparted on it by the feedstock and the production method, an investigation into these variables would help determine what the most effective biochar is to maximise carbon sequestration. Roberts et al. (2010) also found that biochar systems that use agricultural waste or residue as the biomass feedstock are effective carbon sinks, predominantly due to their ability to sequester atmospheric carbon in soil, while also being capable of generating biofuels that can replace environmentally harmful solid fuels. The critical component of the use of biochar to sequester atmospheric carbon dioxide is due to the benefits of increased longevity for the charcoal in the soil. Downie et al. (2011) discusses the use of charcoal in ancient Australian aboriginal oven mounds. These mound, range in age from 650 – 1600 years, resulted in long-term, elevated soil carbon levels when compared to adjacent soil samples. The study suggest that the duration of the carbon sequestration process extends over a long period of time, which is useful in the reduction of greenhouse gas emissions. History and research have shown that the use of charcoal in soil is not limited to one geographical location globally. Although used inadvertently, the presence of charcoal in soil has acted as a mechanism for carbon sequestration. According to a report by Lal (2009), the global hotspots for areas that have a high priority for soil restoration are Central and South China, the Andean region, and the acidic savannahs of South America, some of which coincide with areas of elevated greenhouse gas emissions.

There are four main strategies for carbon sequestration:

**Terrestrial sequestration** – Transferral of atmospheric carbon dioxide into the trees and soils

**Geological sequestration** – Transferral of atmospheric carbon dioxide into abandoned coal mines, aquifers, and oil wells

**Oceanic sequestration** – Injecting of carbon dioxide deep into the ocean, or increasing productivity of the ocean biota through iron fertilisation

**Chemical sequestration** – Precipitation of industrial carbon dioxide as carbonates of calcium or magnesium

Out of all of these strategies, terrestrial sequestration – or carbon soil sequestration – is a natural process, and has proven to be very cost effective while posing low risk to the existing biosphere. Therefore, the use of biochar to achieve the reduction of carbon dioxide in the atmosphere, as well as providing alternative biofuels as by-products, will help mitigate the effects of climate change. Research into maximising the ability of biochar to sequester carbon under various conditions would prove very useful and has scope for further investigation.

3.2.3 BY-PRODUCTS

By-products of biochar have an influence on the overall impact of biochar as sustainable solution to the problems outlined by this project. A production method that can optimise the generation of biochar while also reducing wastage through the utilisation of by-products during the production process can be considered beneficial. The production of biochar through
various methods, always results in the generation – in differing quantities – of two by-products: bio-oil and syngas. The current use of solid fuels has both health and environmental implications for millions of people worldwide. The burning of solid fuels, especially indoors for cooking and heating, results in smoke inhalation and indoor air pollution which causes the deaths of up to 2 million people worldwide every year (UNICEF 2012). Solid fuel use also results in the release of harmful greenhouse gases and particulate into the atmosphere as well, contributing to significant, irreversible climate change. Biochar production generates two by-products through the breakdown of the natural and polymeric constituents of the biomass such as fats and starches that could offer an alternative fuel source to the existing practices: bio-oil and syngas. This literature review will only cover the basics of bio-oil and syngas, whereas the critical literature review to be presented in the mid-project report will consider the most effective production mechanisms for each by-product, as well as a detailed analysis into their respective compositions.

### 3.2.3.1 Bio-oil

During the process of fast pyrolysis, the vapours caused by the high heating rates are quenched rapidly to form a liquid product, bio-oil. The fast pyrolysis process is most effective in creating bio-oil as it creates and separates the vapours rapidly, before they can carbonise as chars or crack into non-condensable gases. In a fast pyrolysis process, moderate temperatures ranging from 400-600°C and a time period of no more than a few seconds are implemented to achieve a maximum yield of up to 70% bio-oil. Bio-oil generated through fast pyrolysis is a complicated mixture of water and over 300 organic compounds. It is comparable to crude oil in the sense that it can be fractionated and upgraded to form biodiesel, and other organic chemicals and transportation fuels (Wang, 2013).

### 3.2.3.2 Syngas

The main process used to produce syngas is the production of biochar through gasification. Syngas (Synthetic gas) consists mostly of carbon monoxide and hydrogen, with small amounts of methane and other hydrocarbons. Syngas can be used as a direct alternative to natural gas (methane). However, syngas is much less energy dense than natural gas, as it contains carbon that has been mostly oxidised. It is possible to manufacture transportation fuels and chemicals from syngas, as well as hydrocarbons through a catalytic process. Depending on the reaction conditions of the catalytic process, syngas can be converted into a range of products such as gasoline, jet fuel, diesel, and wax.

### 3.3 PRODUCTION METHODS

The production of biochar can theoretically be done through the thermochemical processing of any material containing carbon. The biomass used to generate biochar can range from solid wastes, agricultural wastes, vegetation residue, and even unused building materials. The main constraints to the selection is the availability, affordability, and safety of the biomass to be used. There are many ways in which biochar can be produced including, but not limited to, slow pyrolysis, fast pyrolysis, thermos-catalytic depolymerisation, and gasification. This literature review will provide a brief overview on the two most common methods: slow and fast pyrolysis. A more detailed review into each method, as well as investigations into alternative methods will be presented in the critical literature review in the mid-project report.

#### 3.3.1 Slow Pyrolysis

The generation of charcoal is traditionally done through the process of pyrolysis. Pyrolysis refers to the heating of a biomass feedstock in the absence of oxygen, in a range of moderate to high temperatures. The biomass also acts as a fuel, with a portion of the feedstock undergoing combustion to maintain the heat necessary to start and sustain the reaction. The result of slow pyrolysis is an energy-dense, carbon-rich, char. This char is most effective when being used in applications where the carbon is not ‘rapidly remineralised’, i.e. used as fuel and burnt, but rather kept in its stable state for use in carbon sequestration and soil amendment. Slow pyrolysis is characterised by lower temperature ranges (350°C upwards), low heating rates, and increased period of time in which the biomass is combusted. This process is ideal for maximising the yield of biochar, although it results in smaller quantities of by-products (bio-oil and syngas). Traditionally, slow pyrolysis process have been conducted in kilns made in mounds or pits; however, new technologies allow slow pyrolysis to take place in modern kilns that can increase control of the reaction variables, while reducing unwanted emissions. These kilns have the potential to be run for large-scale, efficient biochar production and research into more effective kiln designs will result in modern, clean designs that provide greater consistency and control.

#### 3.3.2 Fast Pyrolysis

Fast pyrolysis is similar in method to the slow pyrolysis process, with the main difference coming from operating temperatures and residence times. In a fast pyrolysis process, the biomass undergoes very fast heating rates to the tune of approximately 100°C per second. In fast pyrolysis, the goal of the method is to create and separate vapours before they can condense. This kinetically controlled reaction happens almost instantaneously, as the fast rate of heat transfer results in immediate drying and volatilisation of the biomass. Fast pyrolysis can be achieved through the use of fluidised beds,
heating blades, or screw mixer reactors. According to data based on Bridgwater (2012); van der Stelt et al. (2011); Williams and Besler (1996); Bain and Broer (2011); Nachenius et al. (2013), fast pyrolysis yields are usually composed predominantly of liquids such as bio-oil (75%), syngas (13%), and char (12%). As the process is endothermic, fast pyrolysis systems use char combustion to provide heat for the process, and do not have a net biochar production (Wang, 2013).

3.4 CHARACTERISTICS

Biochar is a broad term used to describe any type of charcoal placed in soil for an agricultural, or environmental purpose. The physical, chemical, and behavioural characteristics therefore vary between individual biochar samples. Factors such as the biomass feedstock used, the production method, the heating temperatures, and numerous other variables affect the composition and characteristics of the biochar. These characteristics can be altered to give the biochar the properties it needs, for instance, to amend deteriorated soil for a specific condition and environment. As part of the aims of this project, a thorough investigation will be conducted into the various properties of biochar, and the potential characteristics it could impart into the soil. The critical literature review layout in Appendix 10.3 outlines the characteristics that will be covered in detail in the Mid Project report. Presented below is a list of some of the biochar characteristics considered, with a short description of the benefits of possessing that characteristic:

Density – Biochar with a low bulk density helps to reduce the density of soil, which results in improved root penetration (Atkinson et al., 2010). Other benefits include improved water drainage (Joseph et al., 2009); and improved aeration, which helps mitigate greenhouse gas emissions (Kahru et al., 2011)

Surface Area – A high surface area implies the presence of a high micropore specific surface. This allows for a greater likelihood of organic compounds attaching to the biochar (Cornelissen et al., 2005); and an improved water retention capacity (Kahru et al., 2011)

Yield – An effective production method is one that maximises the quantity of biochar produced during pyrolysis.

Electrical Conductivity – A high electrical conductivity has the potential to stabilise the soil structure, due to increased levels of salt content in the biochar (Hossain et al., 2011)

Cation Exchange Capacity – An increased cation exchange capacity can improve the ability of the soil to hold and exchange cations which helps the soil hold key nutrients (Glaser et al., 2002)

pH – The pH levels of the soil directly affect the type of nutrients and minerals it can hold (Mukherjee et al., 2011). A biochar that can be designed to assist the specific needs of the soil will also be beneficial in reducing the acidity and toxicity of the soil (Lehmann et al., 2011)

Ash content – A higher ash content in the biochar allows for an improved capacity in the soil to absorb and retain organic compounds (Cao et al., 2011)

Volatile matter – The amount of volatile matter directly affects the longevity of the biochar in soil (Enders et al., 2012).

Carbon – As discussed at length previously in the literature review, increased carbon content in the soil provides various benefits including carbon sequestration and soil amendment.

Carbon: Nitrogen – The ratio of carbon to nitrogen in the soil directly affects the rate at which organic matter decomposes in the soil, as well as the rate at which nitrogen is released into the soil (Novak et al., 2009).

Macronutrients – Biochar can contain a number of nutrients that can improve soil fertility. These nutrients include, but are not limited to: Phosphorous, sulphur, calcium, potassium, magnesium, sodium, iron, manganese, zinc, nitrogen.
3.5 SUMMARY AND RESEARCH GAPS

The concept of biochar was implemented by pre-Columbian Amazonian tribes all over the amazon basin. The soil, called ‘Terra Preta’, was found to be rich in mineral residue and decomposed organic material which made it fertile enough to sustain continuous crop yields. Biochar has been popularised as a mechanism to aid improve fertility of soil, as well as reduce the effects of climate change by acting as a tool for carbon sequestration in soil. A review of the existing applications of biochar showed that it had basic applications in both agricultural and environmental areas of research.

The effect of biochar on crop productivity was investigated through the review of several field trials conducted in the 1980s and 1990s, and then further researched by Glaser et al. (2001). It was found that biochar addition to soil generally resulted in positive yield effects for crops. Soil function, fertiliser efficiency, and crop yields were all found to improve due to the presence of biochar in the soil. It was concluded that although some data exists, repeatability of the results are needed to affirm the effectiveness of biochar, especially in large scale applications.

The ability of biochar to act as a tool for carbon sequestration has been investigated as a means to mitigate climate change at a global level. Most reports on biochar being used as a carbon sink focus on the role that the loss of natural resources such as rainforests play in increasing greenhouse gas emissions. In this context, the use of biochar performs a dual purpose: improving soil fertility in such areas to encourage plant growth; and sequestering carbon dioxide in the soil, which reduces the emissions in the air as well as enrich the soil.

A review of the various production methods provided some insight into the cost effectiveness, time consumption, advantages, and disadvantages of the different techniques. Slow pyrolysis was found to require very few resources and be the most cost effective, but studies have shown that fast pyrolysis can optimise the yield of useful by-products such as bio-oil and syngas, which can act as alternative fuel sources. Comparing the research on biochar production methods shows the need to optimise a production method that provides the greatest quantity of effective biochar, while also producing usable by-products to ensure the product is as sustainable as possible.

In researching the characteristics of biochar that contribute to its effectiveness, it was found that there was a major focus amongst most studies to focus on one particular type of source feedstock, or one particular area of land with its own unique soil characteristics. A review of existing field tests and research reports found that there was an increased focus on ‘designer biochar’, or biochar designed to be effective for one unique location or purpose. This leaves scope for research to be done on the characteristics of biochar in general. By broadening the focus from ‘designer biochar’ for specific instances, more emphasis can be placed on the individual characteristics that define and influence the effectiveness of biochar. This project will aim to provide substantial analysis of the characteristics involved in producing effective biochar.
4 Aims and Project Objectives

The objective of this project will be to better understand the characteristics of biochar in order to identify optimal production processes. This will be done through the achievement of three specific goals. Firstly, research will be conducted into different methods of generating biochar, encompassing factors such as equipment and feedstock. Biochar will then be produced using the slow pyrolysis method, with batches being created under the effects of certain variables. Ten different samples of biochar will be produced, using five types of feedstock and up to three kilns.

Secondly, the yield of biochar produced using each method will be compared, as well as key aspects such as macronutrients, absorption, and pH levels. This is essential as the effective capacity of biochar reflects how well it can mimic activated carbon, which enhances plant growth. Other relevant aspects for comparison, as outlined by Section 4.4, will be tested and analysed through the course of the project.

Finally, investigations will be conducted from a humanitarian aspect into comparisons that can be made in the production method, with respect to the specific characteristics, in order to find a method that generates the most effective biochar while minimising any negative aspects, such as cost and availability of resources. Consideration will also be given to environmental impact, and quality and quantity of useful by-products generated.

These research goals have been designed with the SMART criteria in mind:

Specific – A research gap in the field exists with respect to the effectiveness of the biochar generated using the different methods, as mentioned above. Emphasis will be put on researching the most effective method in a humanitarian context, i.e. a method that generates the most effective biochar, while also generating less greenhouse emissions, and being affordable and easy to use for the relevant intended users.

Measureable – The effectiveness of the biochar will be determined through both the quantitative and qualitative analysis of the biochar test specimen generated using the different production methods.

Assignable – The testing, compilation, and comparison of results, as well as the research will all be done by the student.

Realistic – It is not realistic to test every production method of biochar possible. This project will focus on only 3 methods of biochar generation. Furthermore, the absorption and adsorption capabilities of the biochar cannot be tested for a large variety of liquids and gases, and will therefore be confined to a medium to be decided by the student and the supervisor during the course of the project.

Time-Related – The initial stage of the project will encompass background research and a literature review. A maximum of 6 months will be used to conduct the testing period over summer. Comparison of results, detailed analysis, and humanitarian improvements into the production methods will be researched will follow in the 2 months following, in time for the completion of the final report in accordance with the Masters Project schedule.

While this SMART criteria takes into account whether the project scope is realistic, and who the project will be undertaken by with respect to the individual tasks, it is important to also consider the following two criteria:

Achievable – This criteria replaces the Realistic requirement in the original SMART criteria, and focuses on whether the project scope can be achieved given the time, resources, and current skill level.

Relevant – This criteria is used to assess whether the goals being targeted by the project hold any relevance to the aims of the project. While it might be interesting to analyse a CFD model of biochar pores to determine fluid flow, it holds little relevance to the aim of experimenting on a broad range of characteristics and researching the humanitarian aspects of biochar production and use. Therefore, the testing phase of the project will focus on relevant characteristics that can be used to effectively compare the various biochar samples. These relevant characteristics have been determined, outlined, and explained in the literature review, Section 4.4.
4.1 Project Constraints:

The project will be subject to a set of constraints that reflect the resources available to the student and the project outcomes detailed in Section 6.2. The project will take a maximum of one year to full completion, as per the university requirements. The one year will encompass a six month testing period; to be undertaken by the student. These tests will be conducted as per the resources available; laboratory tests are at the discretion of the provider and thus laboratory access may not be available at all times to the student, if at all. The entirety of the project should not surpass a total cost of $1500, as specified in the Masters Project guidelines for the University of Adelaide.

The production of the biochar is heavily dependent on the weather conditions; hot and dry conditions have an adverse effect on the ability to fire a kiln. The production of the biochar will be carried out at a property in Macclesfield, in the Adelaide Hills. CFS fire ban regulations limit the ability to fire kilns in hot and dry conditions, which made up a majority of the six month testing period. Fortunately, through careful planning and fortunate rainfall on certain days, this problem was overcome and the necessary samples were produced. However, this affected the timeline of the project and created some scheduling conflict in the Gantt chart that was ultimately overcome.

Another constraint to the project was the need to limit the complexity and cost of any equipment used in the biochar production phase. In taking a humanitarian approach to the project, a conscious decision was made to avoid any resources or equipment not readily available to people in disadvantaged, agricultural countries. Therefore, the kilns and feedstock had to be of a simple design, reproducible, and easily accessible.
5 Project Management

This section describes and justifies the development strategy chosen for the project. It describes the approaches, methods and techniques to be used during the requirements specification, implementation, verification, validation and test.

5.1 Project Requirements

The following are a list of requirements that must be met before the project can be deemed completed. These requirements are only necessary to determine whether the project has been completed; the success or failure of the outcomes are dependent on the extent and quality of the analysis and research presented.

1. Detailed research must be completed on the existing knowledge in the field of biochar
2. The logistics of production, testing, and analysis must be sourced in order to conduct the experiments
3. Biochar production must be conducted under varying conditions (as specified in Monitoring Mechanisms) including but not yet limited to: feedstock, duration of pyrolysis and temperature at which pyrolysis will take place.
4. The biochar must be tested for any relevant characteristics for the sake of comparison between samples.
5. The experiments must be monitored at regular intervals and data must be collected
6. A qualitative and quantitative analysis must be conducted on the retrieved data
7. A report must be compiled to publish the findings of the analysis and present further improvements

These requirements must all be met whilst completing the project management aspect, which includes compiling and presenting various deliverables such as the project proposal, the project definition statement and plan, the mid project report, the seminar presentation, and the final report.

5.2 Project Outcomes

This section provides a detailed outline of all the deliverables the project will produce. These include content produced during the length of the project, as well as deliverables required from a project management aspect. The project outcomes, and the time frames involved in conducting them, are expanded upon in the Work Breakdown Structure in Section 7.1 and Appendix 10.2

1. Project Proposal
   A document written at the start of a project to initiate a formal description of the project aims, objectives, and deliverables. It also describes how the project is substantially research based in order to satisfy the AQF Level 9 Requirement.

2. Project Definition Statement and Plan
   The project definition statement clearly states the aims and objectives of the work, along with the expected outcomes and project requirements. The plan describes how these outcomes will be achieved, with a detailed focus on milestones, deliverables, and required tasks.

3. Mid Project Report
   A report that reflects work in progress at the halfway point of the project timeline. Essential to allow the student and supervisor to monitor progress, indicating to the likelihood of a successful project.

4. Final Report
   Similar to the Mid Project Report, builds on the work done during the previous three deliverables and documents the concluded project journey.

5. Seminar
   A presentation that showcases the background, literature review, and results of the project. It is essential in allowing the examiners to assess the technical presentation skills displayed, as well as clarify any necessary details. A successful seminar presentation satisfies the AQF Level 9 requirements for oral communication skills.

6. Research
   The research outcomes for this project encompass a detailed literature review that acts as a foundation for the project to explore methods of testing, analysis, and future research. A more detailed breakdown of the research component of the project is viewable in the Gantt chart in Appendix 10.1. The research phase of the project will also be implemented post-analysis while determining future work with respect to humanitarian improvements.
7. Testing
The testing phase of the project will result in the collection of data and key components for both a quantitative and qualitative analysis in order to conduct an effective analysis. The data collected for a preliminary analysis will include the biochar characteristic analysis, and will be presented in the Mid Project Report. The final set of data to be collected and analysed for the Final Report will include the biochar characteristic data.

8. Analysis
The data collected during the testing phase of the project will be analysed and subsequently used to compare the various biochar samples. This allows for the various samples to be ranked in terms of effectiveness, thus successfully achieving one of the key outcomes of the project.

5.3 Justification Project Addresses Research Based Requirement
The Australian Qualifications Framework (AQF) Level 9 requirement states that this Masters Project must satisfy the following condition:

“Research comprises systematic experimental and theoretical work, application and/or development that results in an increase in the dimensions of knowledge.”

This project encompasses research significant to real world applications, as it is important to maximise crop yield in areas that require effective use of land. Research currently exists on how biochar is created but, as specified in the introduction in Section 2, there is a research gap in biochar production with a humanitarian emphasis. Finding an improved production method that generates effective biochar, while minimising any negative environmental impact will increase the use of alternative fuel sources, and improve the efficiency of agricultural practices around the world. The theory behind biochar and its production methods will be researched and furthered through testing and analysis of the results, and thus, meets the AQF Level 9 requirement for the Masters by Coursework project.

5.4 Risk Analysis
This section describes potential risks to the success of the project outcomes. The various problems include damage to the experiment, unavailability of resources or equipment, or any technical problems incurred during the length of the project. The risk register included takes into account the likelihood of something happening, the relative consequence, the risk level, whether the risk is acceptable, and any potential prevention methods that can be applied. A more detailed explanation of the criteria is outlined below.

<table>
<thead>
<tr>
<th>Letter</th>
<th>Designation</th>
<th>Explanation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>Almost Certain</td>
<td>Highly likely to happen</td>
</tr>
<tr>
<td>B</td>
<td>Likely</td>
<td>Will probably happen</td>
</tr>
<tr>
<td>C</td>
<td>Possible</td>
<td>Might happen occasionally</td>
</tr>
<tr>
<td>D</td>
<td>Unlikely</td>
<td>Not expected to happen</td>
</tr>
<tr>
<td>E</td>
<td>Rare</td>
<td>Unlikely to happen</td>
</tr>
</tbody>
</table>

Table 1: Likelihood Designation
**Consequence**

The consequence scale will have five levels, as shown in Table 2. The consequence level in the risk register follows the consequence descriptions outlined below.

<table>
<thead>
<tr>
<th>Rating</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extreme (5)</td>
<td>The project is compromised to such a level that it cannot be completed</td>
</tr>
<tr>
<td>Major (4)</td>
<td>The project is permanently compromised to a significant level</td>
</tr>
<tr>
<td>Moderate (3)</td>
<td>Significant setback. Will require lots of work to overcome, but little to no permanent damage done to project outcomes</td>
</tr>
<tr>
<td>Minor (2)</td>
<td>Setback requiring a moderate amount of effort and time to overcome</td>
</tr>
<tr>
<td>Insignificant (1)</td>
<td>Setback requiring a small amount of effort or time to overcome</td>
</tr>
</tbody>
</table>

**Risk Matrix**

The risk matrix is used to determine the level of risk rating for a listed risk. Table 3 shows the management required for each risk level to ensure no damage is done to the success of the project outcomes.

<table>
<thead>
<tr>
<th>Likelihood</th>
<th>Consequence</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1 Insignificant</td>
</tr>
<tr>
<td>A Almost Certain</td>
<td>Medium</td>
</tr>
<tr>
<td>B Likely</td>
<td>Low</td>
</tr>
<tr>
<td>C Possible</td>
<td>Low</td>
</tr>
<tr>
<td>D Unlikely</td>
<td>Low</td>
</tr>
<tr>
<td>E Rare</td>
<td>Low</td>
</tr>
</tbody>
</table>
### Table 4: Risk Management Plan

<table>
<thead>
<tr>
<th>Risk Rating</th>
<th>Management Plan</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>Manage and review as necessary</td>
</tr>
<tr>
<td>Medium</td>
<td>Assess the risk; determine if further action or treatment is necessary</td>
</tr>
<tr>
<td>High</td>
<td>Risk given appropriate attention and management; reported to senior management committees as necessary</td>
</tr>
<tr>
<td>Extreme</td>
<td>Immediate attention and response needed; requires risk assessment and management plan prepared by senior management committees</td>
</tr>
<tr>
<td>RISKS TO PROJECT SUCCESS</td>
<td>LIKELIHOOD</td>
</tr>
<tr>
<td>--------------------------------------------------------------------------------</td>
<td>------------</td>
</tr>
<tr>
<td>Equipment sourcing: Test and measuring equipment can't be sourced</td>
<td>C</td>
</tr>
<tr>
<td>Testing method sourcing: No access to a lab that can conduct relevant tests</td>
<td>C</td>
</tr>
<tr>
<td>Cannot source biochar, or biochar making equipment</td>
<td>D</td>
</tr>
<tr>
<td>Data loss: Accumulated project data damaged or lost due to technical issues</td>
<td>E</td>
</tr>
<tr>
<td>Biochar of poor quality: The biochar might not provide any useful test results</td>
<td>E</td>
</tr>
<tr>
<td>Risk of fire while producing biochar</td>
<td>E</td>
</tr>
</tbody>
</table>
5.5 Monitoring Mechanisms

The project will be monitored using a range of mechanisms determined by both the university and the student. Reports will be completed and submitted to the supervisor and a panel of secondary persons to ensure the progress of the project meets the expectations of the university. Reports will include this document – encompassing a project definition statement and plan, a mid-project report, final-project report and a report on the entirety of the project from the student in the form of a seminar. The progression and results of the physical outcomes of the project will be reported using resources available to the student. These resources should include; a laboratory for the student to undertake characteristic tests of biochar, a kiln in which the pyrolysis of the feedstock will be conducted to produce the biochar for characteristic tests, samples of feedstock (both determined and sourced by the student) for production of biochar and a storage facility in which the student may store the resources and equipment for the duration of the testing and analyses phases of the project.

As a comparative analysis of biochar is required for this project, a number of factors must be controlled and/or varied. Initially, it was deemed important that the feedstock used for biochar production remain consistent throughout the production period. However, as the project scope changed, it was decided that the samples would use a range of feedstock types for production and testing. The temperatures at which pyrolysis will take place for each feedstock was initially planned to be varied incrementally, but this was deemed to be unrealistic given the equipment and resources at hand. The duration of the pyrolysis period was another factor of comparison that was determined to be out of the scope of the project work. The control of factors such as temperature and burn time is dependent on the quality and the complexity of the kiln designs, which proved to be too expensive to buy or too complex to design given the predefined budget and time constraints on the project.

As a comparative analysis of biochar is required for this project, a number of samples were produced with factors that were controlled and/or varied. Five different types of feedstock will be tested, as this will provide a broader range of results for the comparative testing. The temperatures at which pyrolysis will take place for each feedstock cannot be controlled, but each test will be conducted in a range of three different kilns, all of which operate within a certain temperature range. These factors will also be repeated appropriately for each testing phase. The quantity of feedstock should not be constrained as a comparative analysis of the biochar quantity after pyrolysis will be conducted on a relative basis; the amount produced will be compared to the quantity of feedstock used and thus will be a percentage of feedstock. A more detailed outline of the various factors in the production and testing phases of the project are outlined in Section 6.
6 Experiments

6.1 Introduction

The aim of this report is the production and analysis of biochar samples in order to determine the characteristics effective in developing efficient biochar. The process leading to a useful analysis and procurement of usable data begins with the production of the biochar samples themselves. As discussed previously, the biochar samples will be generated in a variety of kilns using different types of feedstock. The samples will then be subjected to a battery of tests to determine how their characteristics are influenced by the production methods and feedstock used; the connection between the characteristics and the efficiency of the samples will also be investigated. The following sections will outline the experiments to be conducted in order to generate and test the biochar.

6.2 Production

Before any testing or analysis can occur, the biochar samples themselves have to be generated. The process used to create these samples is referred to as slow pyrolysis. As discussed in the literature review, slow pyrolysis is a method in which a biomass is combusted in the absence of oxygen in a range of medium to high temperatures. For this project, numerous samples of biochar will be produced, varying in terms of the equipment and the feedstock used to complete the pyrolysis process. The biochar was generated at the property of Greg Marlu in Macclesfield, south of Adelaide. Mr. Marlu runs a grass roots business, SA Biochar Works, in the Adelaide Hills and has been creating his own biochar from local timber waste for the use of home gardeners for the past few years.

Once the logistics of production were finalized, multiple samples of biochar were generated. Initially, the scope of the project allowed for samples to be produced at three different temperatures within the slow pyrolysis range. Each temperature-based sample was then to be split up into three further groups dependent on the time taken for the pyrolysis process. For example, for the first goal of this project, biochar will be produced at 400°C, 550°C, and 700°C, with each temperature containing samples combusted for 4, 6, and 8 hours, thus providing nine batches of biochar for testing and comparison. During the production phase of the project however, it was found to be a non-viable approach, as specific control of temperatures and burn times was heavily dependent on the use of complex, expensive machinery. As a result, the biochar samples produced were instead varied by the use of different feedstock and kilns. Five different types of feedstock and up to three different kilns were used to generate a total of ten sample batches.

A.1.1 Equipment

In the production phase of the project, the only equipment used were the kilns used to generate the biochar. In order to maintain the humanitarian approach taken by the project work, the kilns reflected the ideas of simplicity and resourcefulness. All the kilns used to produce biochar for this project can be easily reproduced with scrap materials and basic tools. The kilns became one of the major independent variables in the latter stages of the project, replacing temperature control. This was due to the complexity involved in accurately controlling temperatures with simple instruments. The generated heat would ideally be maintained at an optimized temperature to maximize carbonization, and the biochar samples generated at different temperatures would have been compared. But as that would require complex equipment costing thousands of dollars, making it inaccessible to people in impoverished agricultural communities, the temperature variance would have to be derived from the kilns being used. Each type of kiln has a different operational temperature, and the subsequent effect on the biochar samples has been documented and presented in Section 7.3 and Section 8.2.
Top Lit Up Draft Kiln

Figure 1 Top Lit Up Draft (TLUD) kilns manufactured by SA Biochar Works

The first kiln used for the production of biochar samples was modelled as a Top Lit Up Draft (TLUD) kiln. The TLUD design was conceptualised by Dr. Thomas Reed in 1985 and can be classified as a gasifying micro-kiln. Figure 2 shows a cross section view of a standard TLUD kiln.

Figure 2 Cross Section View of a TLUD kiln (Source: http://www.biochar-international.org/sites/default/files/fan%20gasifier%20stove.png)

Consisting of two concentric cylinders, a TLUD kiln pyrolyses the feedstock by drafting air through holes at the bottom of both cylinders, which fuels the fire lit at the top of the inner cylinder. The design of the TLUD kiln is such that the fire is lit at the top of the cylinder full of feedstock. The layer of burning feedstock at the top, referred to as the primary layer, is used to combust the layer below (secondary layer). As the secondary layer is devoid of oxygen in the process, the feedstock is turned into biochar as the primary layer moves its way down the cylinder (Kshirsagar and Kalamkar, 2014).

Figure 3 The inside of a homemade TLUD kiln
The TLUD kiln used for this project was built by Mr. Greg Marlu (SA Biochar Works) and features three main components. The first component is an oil drum with holes drilled at the base (FIGURE 3), the second component is a removable chimney (FIGURE 5) placed on top of component three, a lid with air intake holes (FIGURE 4). The oil drum, with a capacity of 200 L, stands on the ground raised slightly by bricks. When the feedstock fills the drum, the lid is placed on top and the chimney is attached. A butane torch is used to light the feedstock at the top through the air intake holes in the lid.

As temperature level is not a viable method of control for the kiln, the heat input is controlled by the opening and closing of the air intake holes. If the temperature is too high, there is a high chance of the feedstock turning to ash. When the feedstock is pyrolysed, smoke is produced and released through the chimney. White smoke is indicative of the feedstock drying off and the combustion process beginning; once the smoke turns clear, the pyrolysis process is underway. At this point, the air intake vents can be closed as the heat from the primary layer of burning feedstock is enough to sustain the process through to completion. The entire pyrolysis process in a TLUD kiln is undertaken at a temperature range of approximately 500 to 600 degrees Celsius.
Earth Kiln

The second kiln utilizes the simplest possible method used to produce biochar. Basic earth kilns were the forerunners of modern kiln designs, due to their simplicity and accessibility. An earth kiln is just another term for a hole in the ground used to pyrolise feedstock. Figure 6 shows the earth kilns used to produce a few of the biochar samples used for this project.

![Earth kiln](image)

Figure 6 Simple Earth kilns dug into the ground

The foremost benefit of using earth kilns comes from eliminating the need to transport the feedstock to the kiln. As feedstock can range from straw to trees and branches, the ability to have a kiln at any location is a huge advantage to the production of biochar, as a user can create a kiln right next to the feedstock source. The only things required to create this design are a shovel, and a willingness to get ones hands dirty. A hole is dug, and an earth mound is created around the edges to protect the pyrolysis from outside air. This most rudimentary of designs has been utilized in the Amazon basin as early as 5000 years ago, and remains popular in Africa to this day (Garcia-Perez et al., 2010).

![Figure 7 Earth kiln emitting smoke](image)

Figure 7 Earth kiln emitting smoke

As with the TLUD kilns, the primary technique used to monitor the pyrolysis process is through the observation of smoke being released. The initial smoke is quite thick and white, to indicate the combustion of the feedstock in order to start the pyrolysis process. The drawback of using such a technique is that it leaves the user open to smoke inhalation, which – depending on the amount of moisture in the feedstock – can be quite severe and harmful.
Kon tiki Kiln

The concept of a kon tiki kiln acts as a hybrid design between the earth kiln and the TLUD kiln. It is a portable version of an earth kiln, made from scrap metal and welded together to form an artificial ‘pit’ in which to pyrolyse feedstock. The kon tiki kiln in Figure 8 was built by Mr. Greg Marlu, and used to generate just a single sample of biochar. While this sample wasn’t subjected to the same extent of tests as the others, it was tested nonetheless as a real world example of how biochar could be produced.

![Homemade Kon tiki kiln](image)

Figure 8 Homemade Kon tiki kiln

The kon tiki kiln, when transported in a trailer, is an easy way to move the kiln to the source feedstock (which in this case was an assortment of tree branches from nearby trees). The branches are then piled loosely into the kiln, and a fire is lit on the top layer, much like a TLUD kiln. Heat radiating from the primary layers then burns the branches in the secondary layer, and so on until the entire pyrolysis process is complete. Air is drafted into the fire through the side of the pile, similar to the earth kiln, and is drafted up into the flame. This leaves the feedstock with a deficit of oxygen, thus mostly preserving the char (Fuchs et al., 2014). The char is then released into the trailer through a gate at the base of the kiln.
A.1.2 Feedstock

In an effort to concentrate on feedstock sources that are easily accessible to a rural, agricultural demographic, the feedstock types tested for this project were all sourced locally in the Adelaide Hills area. A total of five types of feedstock were tested in the TLUD kiln and the earth kiln, with sticks and branches also used in the kon tiki kiln for the sake of comparison.

**Sticks and Branches**

The first type of feedstock tested were sticks and branches that fell from trees surrounding the property in the Adelaide Hills, where the kiln was located. The feedstock included branches from pine, eucalypt, and acacia trees scattered around the property. All branches were broken down into smaller pieces by hand in order to fit them into the TLUD and earth kilns; the kon tiki kiln used full branches as feedstock as it was a larger sized kiln.

**Leaves and Twigs**

The next type of feedstock tested were leaves and twigs, also from pine, eucalypt, and acacia trees in the surrounding area. Foliage was collected in a wheelbarrow, left to dry out, and then packed into the TLUD and earth kilns. The smaller size of the feedstock particles would imply that the burn time would be much shorter than the branches and sticks, subsequently resulting in greater ash content. The results for the feedstock tests are displayed and discussed in Sections 7.3 and 8.
Pea Straw

The pea straw used to make biochar for this project came in the form of compressed bales and were purchased from a local hardware store. Pea straw is used as a natural mulch in gardens due to its increased ability for water retention. Pea straw is also the least dense of all the feedstock used, which would suggest that it would burn the fastest.

Wood Chips

Branches from eucalypt, wattyl, acacia, sheoak, and pine trees were processed through a wood chipper to produce the wood chips used to produce biochar for this project. This assorted mix of woodchips is representative of bags of wood chips readily available for purchase at hardware stores. However, the wood chips used for this project were produced locally at the test site in the Adelaide Hills, and consequently reflect the local tree growth.

Red Gum Wood Chips

Finally, a pure sample of wood chips sourced only from red gum trees was also used as feedstock in the kilns. These red gum wood chips were obtained through a local hardware store, and came pre-packaged in plastic bags. As a result, this feedstock had a higher level of trapped moisture than wood chips left out in the open. The effect of higher moisture in the feedstock is discussed in Section 8.2.
6.3 Testing

In order to test, analyse, and compare the various biochar sample batches, certain parameters will be used to determine biochar effectiveness. These parameters all have an effect on the performance of the biochar, as research has shown in the literature review. An effort has been made to design experiments to test these characteristics with local resources and equipment in order to increase the level of control and versatility during the testing and analysis phase of the project for the student, as opposed to outsourcing the tests and analysis. However, this is not always possible, either due to a lack of equipment or the complexity of the test required. In these cases, contact will be made with laboratories and institutions deemed capable of competently undertaking the experimentation required in order to procure the data required to successfully complete the project. The following sections outline the primary testing method used to evaluate the respective characteristic.

A.1.3 Yield

Testing the production quantity of each batch of biochar is a straightforward process that involves weighing the input of biomass prior to the pyrolysis process, and then weighing the biochar output. The masses of the input and the output can then be expressed as a percentage to determine the yield of each sample.

A.1.4 By-products

The ash content and by-product volume of each sample is directly related to the yield. The total volume of the feedstock input, less the biochar yield would give a relevant figure for the ash content. Due to the simple, cost effective nature of the equipment being used, measuring the ash content would prove to be inaccurate with regards to the available resources and facilities allocated to this project. Although this technique doesn’t differentiate between by-products such as bio-oil, tar, or syngas, it is applied to all the samples to keep the results relatively consistent between the biochar samples.

A.1.5 Absorption

The ability of biochar to absorb water provides a good correlation of the biochar sample’s cation exchange capacity, which allows it to hold macronutrients and water in the soil. In order to test this, a set volume of biochar will be first be measured. This biochar will then be left in a flask of water, and after a certain amount of time the flask will be drained. The difference in water remaining as compared to the initial amount will be calculated and represented as a percentage to show how much water was absorbed by the biochar sample. The volume of biochar used, the volume of water used, and the amount of time for absorption will all be kept identical for each of the biochar samples to ensure consistency across the tests.

A.1.6 C/H/N Analysis

Measuring the carbon content, carbon to nitrogen (C/N) ratio, and micronutrients present in the biochar samples will be done through the use of a CHN analyser. Dr. Tony Hall from the School of Physical Sciences at Adelaide University will provide the equipment to be used for the testing. The process involves grinding the samples to a fine powder, placing them in tin receptacles, and processing them through a CHN analyser which vaporizes the sample while collecting data on its composition. The machine is calibrated with a standard to ensure accuracy of results. Two tests will be run for each sample to ensure more precise results.

A.1.7 pH

The pH levels of the samples can be tested using basic testing methods involving the use of a pH meter to measure the acidity of a solution containing powdered biochar and demineralised water.
7 Results

7.1 Introduction

Following the planning of the testing phase of the experiment, the biochar was produced and analyses were run. The following section outlines the outcomes of both the production and the testing phases of the project. Section 7.2 covers the results of the production phases, and explains the specifics and differentiating qualities of each sample. The results from the testing phase are shown in Section 7.3. The tests from absorption, pH levels, and the CHN analyses are all included in this section. Section 7.4 shows a complete summary of all results accumulated over the course of the testing period of the project. The implications and inferences from the results of these tests are discussed in Section 8.

7.2 Biochar Samples

In order to keep the results concise and easy to read, Table 6 below shows a summary of each sample, the approximate time taken to produce the sample, and the type of feedstock and kiln used to generate the sample. Sample 10 was produced independently by Mr. Greg Marlu of SA Biochar Works and brought into the project at a later stage, and as a result, is not included in a few of the physical tests. This is because the sample was not produced under test conditions, and therefore lacks details with regards to feedstock quantity used and time taken. Sample 10 has however been included in certain tests such as Absorption, pH, and the CHN analysis.

<table>
<thead>
<tr>
<th>Sample</th>
<th>Time</th>
<th>Feedstock</th>
<th>Kiln</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>1 hr 30 mins</td>
<td>Sticks and Branches</td>
<td>Earth Kiln</td>
</tr>
<tr>
<td>2</td>
<td>1 hr 10 mins</td>
<td>Sticks and Branches</td>
<td>TLUD Kiln</td>
</tr>
<tr>
<td>3</td>
<td>1 hr 5 mins</td>
<td>Leaves and Twigs</td>
<td>TLUD Kiln</td>
</tr>
<tr>
<td>4</td>
<td>20 mins</td>
<td>Pea Straw</td>
<td>TLUD Kiln</td>
</tr>
<tr>
<td>5</td>
<td>2 hr 5 mins</td>
<td>Wood chips</td>
<td>TLUD Kiln</td>
</tr>
<tr>
<td>6</td>
<td>1 hr 10 mins</td>
<td>Red Gum</td>
<td>Earth Kiln</td>
</tr>
<tr>
<td>7</td>
<td>1 hr 35 mins</td>
<td>Leaves and Twigs</td>
<td>Earth Kiln</td>
</tr>
<tr>
<td>8</td>
<td>23 mins</td>
<td>Pea Straw</td>
<td>Earth Kiln</td>
</tr>
<tr>
<td>9</td>
<td>3 hr 10 mins</td>
<td>Red Gum</td>
<td>TLUD Kiln</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>Assorted</td>
<td>Kon Tiki Kiln</td>
</tr>
</tbody>
</table>
7.3 Test Results

A.1.1 Yield Results

The yield of biochar refers to the amount of biochar produced from an initial volume of feedstock. The yield for samples 1 through 9 has been expressed as a percentage of the feedstock input. The initial feedstock volume varied depending on the kiln used. For the TLUD kilns, an initial volume of 200 L filled up the kiln, whereas the earth kilns were dependent on the size of the hole dug for the process. Therefore, expressing the resulting yield as a percentage provides objective results. Sample 10, as mentioned earlier, was not measured for an initial input or a final biochar production volume. Thus, no results for yield are available for Sample 10.

![Yield (%) Volume]

A.1.2 Absorption Results

The absorption abilities of the biochar samples is an indication of their water and nutrient retention capabilities. In order to test the absorption of all the samples, a 50 mL volume of each sample was placed in a beaker containing 200 mL of water. The beakers were then left to sit for 120 minutes under the same conditions, i.e. same room temperature and sunlight exposure. The water was then separated from the biochar and measured again. The final volume was then recorded and the absorbed water was expressed as a percentage in order to determine the absorption capability of each sample.

![% ABSORPTION]

Figure 9 Yield by % Volume

Figure 10 Absorption by % Volume of Water
A.1.3 By-products Results

As mentioned in Section 6.3, testing for ash content would prove to be quite inaccurate with the basic equipment available. Proper ash content testing is explored in Section 9.1, Future Work. Therefore, the by-product tests measured here acts as a corollary to the ash content tests. The percentage of the feedstock not turned into biochar, comprising unburnt feedstock and by-products such as bio-oil, tar, and syngas is represented by the by-products results presented here. As mentioned earlier, Sample 10 had no initial or final volume data available for analysis, and as a result, is not presented in this section.

![By-products Results Graph](image)

Figure 11 By-products by % Volume of Feedstock

A.1.4 C/H/N Results

A CHN analyser is an instrument used to determine the elemental composition of a sample. One such instrument from the Adelaide University School of Physical Sciences was used to determine the levels of Carbon, Nitrogen, and Hydrogen present in each sample. Two tests were conducted for each sample and an average of the results were recorded as the final value in order to minimize errors. A standard was used in between each run of 10 samples to calibrate the system. The raw data output from the CHN analyser can be found in Appendix 2.
An individual comparison of the carbon, hydrogen, and nitrogen contents in each sample is represented below. Notable outliers include Samples 4 and 8, both Pea Straw based biochar samples, having a much lower level of Carbon, and a much higher level of Hydrogen than the other samples.
Figure 12 Carbon Content of Biochar Samples

Figure 13 Hydrogen Content of Biochar Samples
Figure 14: Nitrogen Content of Biochar Samples

Figure 15: Carbon to Nitrogen ratio of Biochar Samples
A.1.5 pH Results

The pH level of biochar can contribute to how well it can perform as a soil amendment tool. To test for the pH levels of the biochar, 20 grams of each sample was added to 250 mL of demineralized water. The biochar was then mixed into the water and allowed to sit for 20 minutes. Three measurements were taken of each sample using a calibrated pH testing device, and then averaged to provide a data point for each sample.
### 7.4 Results Summary

A collection of the results of all the tests performed on the 10 samples of biochar is presented in the table below.

<table>
<thead>
<tr>
<th>SAMPLE</th>
<th>YIELD</th>
<th>BY-PRODUCTS</th>
<th>CARBON</th>
<th>HYDROGEN</th>
<th>NITROGEN</th>
<th>pH</th>
<th>ABSORPTION</th>
<th>C:N RATIO</th>
<th>H:C RATIO</th>
<th>BURN TIME (mins)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>6%</td>
<td>90%</td>
<td>59.285</td>
<td>3.095</td>
<td>0.59</td>
<td>9.56</td>
<td>12.5%</td>
<td>100.48</td>
<td>0.05</td>
<td>90</td>
</tr>
<tr>
<td>2</td>
<td>2%</td>
<td>94%</td>
<td>57.86</td>
<td>2.75</td>
<td>0.66</td>
<td>9.67</td>
<td>17.5%</td>
<td>87.67</td>
<td>0.05</td>
<td>70</td>
</tr>
<tr>
<td>3</td>
<td>2%</td>
<td>93%</td>
<td>52.69</td>
<td>2.395</td>
<td>0.705</td>
<td>9.87</td>
<td>12.5%</td>
<td>74.74</td>
<td>0.05</td>
<td>65</td>
</tr>
<tr>
<td>4</td>
<td>2%</td>
<td>93%</td>
<td>13.74</td>
<td>6.15</td>
<td>0.29</td>
<td>10.04</td>
<td>22.5%</td>
<td>47.38</td>
<td>0.45</td>
<td>20</td>
</tr>
<tr>
<td>5</td>
<td>14%</td>
<td>82%</td>
<td>57.87</td>
<td>3.32</td>
<td>0.475</td>
<td>9.74</td>
<td>12.5%</td>
<td>121.83</td>
<td>0.06</td>
<td>120</td>
</tr>
<tr>
<td>6</td>
<td>10%</td>
<td>85%</td>
<td>60.965</td>
<td>3.27</td>
<td>0.24</td>
<td>9.33</td>
<td>12.5%</td>
<td>254.02</td>
<td>0.05</td>
<td>70</td>
</tr>
<tr>
<td>7</td>
<td>25%</td>
<td>71%</td>
<td>28.835</td>
<td>2.005</td>
<td>0.5</td>
<td>9.52</td>
<td>10.0%</td>
<td>57.67</td>
<td>0.07</td>
<td>90</td>
</tr>
<tr>
<td>8</td>
<td>12%</td>
<td>84%</td>
<td>17.185</td>
<td>7.49</td>
<td>0.65</td>
<td>9.91</td>
<td>20.0%</td>
<td>26.44</td>
<td>0.44</td>
<td>23</td>
</tr>
<tr>
<td>9</td>
<td>35%</td>
<td>62%</td>
<td>58.92</td>
<td>2.48</td>
<td>0.11</td>
<td>9.39</td>
<td>12.5%</td>
<td>535.64</td>
<td>0.04</td>
<td>180</td>
</tr>
<tr>
<td>10</td>
<td>-</td>
<td>-</td>
<td>73.205</td>
<td>2.045</td>
<td>0.295</td>
<td>9.56</td>
<td>7.5%</td>
<td>248.15</td>
<td>0.03</td>
<td>-</td>
</tr>
</tbody>
</table>
8 Discussion

8.1 Introduction

The raw data and results presented in Section 7, on their own, don’t provide any significance to the advantages and disadvantages of the relevant characteristics. The implications of the data, as well as comparisons to existing research will be made in this section. The discussions have been organized by characteristic, by feedstock, and by the production method used. Comparisons have also been made to existing research in the field in order to determine how the rudimentary equipment and production methods used in this project compare to more expensive and complicated machinery. The importance of using basic methods and equipment, as well as the ideal biochar for rural and agricultural communities are discussed.

8.2 Comparisons

A.1.1 Yield

A comparison of the relative yields of all biochar samples reveal some interesting trends. Three of the four highest yields all come from using woodchips as a feedstock. Sample 5 uses an assortment of wood chips and Samples 9 and 6 use red gum wood chips. The three lowest yields come from using sticks and branches (Sample 2), leaves and twigs (Sample 3), and pea straw (Sample 4). Research of existing technologies shows that the yield ranges for earth and TLUD kilns can range anywhere between 2% and 32% (Ronsse et al., 2013). It is not uncommon for biochar yields to be in the range upwards of 40%, but that is limited to biochar produced using complex production mechanisms and held under specific burn times and temperatures (Masek et al., 2013). Using data from experiments conducted by Masek et al., and comparing with biochar produced in the temperature range of 400 – 600 degrees Celsius (the approximate range of temperatures used in this project), the average yield of the feedstock was found to be 30% on average.

As measuring the quantity and quality of the by-products was beyond the means and scope of the project work, the remainder of the initial feedstock not accounted for by biochar yield can be attributed to the production of bio oil, syngas, and ash.

When assessing any patterns with relation to the type of kiln or the type of feedstock used, Figures 19 and 20 below show that there aren’t any noticeable trends towards the larger value of yields. However, at the lower end of the scale, a noticeable feature of the results is that the three lowest yields all come from using the TLUD kilns. This on its own should not be taken as proof of fact that TLUD kilns are inefficient, as the highest yield is also obtained from a TLUD kiln. Comparing the two colour coded graphs shows that the three lowest yields by kiln, and the three lowest yields by feedstock type are both from the same three samples (Samples 2, 4, and 3 respectively). The reason for this can be explained by considering the kiln size and the feedstock density. Samples 2, 4, and 3 are comprised of sticks and branches, pea straw, and leaves and twigs respectively. All these samples have the least density of the feedstock used. As a TLUD kiln can take 200 L of feedstock, there would be 200 L of low density feedstock ready to burn in the kiln. Such a high volume of easily flammable feedstock would result in higher burn temperatures, and consequently, the kiln burning through most of the feedstock before producing any meaningful amount of biochar.

A Figure 18 Sample Yield
Figure 19 Yield Colour Coded by Kiln

Figure 20 Yield Colour Coded by Feedstock Type
A.1.2 Absorption

Tests for the absorption capabilities of the biochar samples showed fairly consistent values across the samples, with two notable exceptions coming from samples 4 and 8. The two highest samples in terms of absorption both come from using pea straw as a feedstock. The lowest value for absorption for the samples came from the kon tiki kiln using an assortment of various branches from the local Adelaide Hills. While the trees used for the feedstock, such as Eucalypt and Acacia, have a high water retention capacity, it would appear that biochar made from these sources does not have an equally effective water retention capacity. The importance of the ability of biochar to retain water comes from the fact that when biochar is added to soil, studies have shown that the water holding capacity of the soil also increases (Dugan et al., 2010). This can be attributed to the ability of biochar to improve the structure of the soil, which allows the soil itself to hold water and nutrients more effectively. Additionally, the biochar itself can hold water in its pores, which increases the overall amount of water in the soil (Jindo et al., 2014). Pea straw is naturally used as a mulch due to its excellent water retention capacity, so it would appear that this ability is translated to the biochar as well.

Upon closer inspection, there appears to be a correlation between the levels of hydrogen present in the sample and the absorption capability of that sample. There are many factors that can influence the water holding capacity of biochar, including porosity, surface area, and surface functional groups (Zhang and You, 2013). A surface functional group is a group of atoms that determine the way a compound behaves physically and chemically; a study by Pastor-Villegas et al. (2010) infers that surface functional groups in biochar are connected to water adsorption capacity. The primary mechanism through which adsorption occurs on the surface and in between molecules is through hydrogen bonds, which explains the correlation between hydrogen levels and absorption capability (McLaughlin et al., 2012).
Figures 23 AND 24 above show no apparent distinction between kiln types when it comes to absorption capabilities of the biochar samples. By looking at the colour coded feedstock graph above, it can be seen that samples with the same feedstock behave the same, regardless of the kiln types used. The grouping of the coloured bars suggests that pea straw as a feedstock tends to retain its water retention ability when turned to biochar. An interesting feature of the results indicates that within the feedstock type, the TLUD kiln consistently produces more absorptive biochar than the Earth kiln variant. The arrows connecting the two graphs highlight this trend with two such feedstock, and it is consistent throughout the data set; given the same feedstock, TLUD kilns produce biochar with a greater level of water absorption than Earth Kilns.
A CHN analyser was used to measure the levels of Carbon, Hydrogen, and Nitrogen present in each of the biochar samples. Figure 25 below show the relative values of each element superimposed on one graph. Merely the level of individual elements in the samples does not provide enough context to the data; comparisons of relative contributions by the elements can provide some useful information. Graphs representing the Carbon to Nitrogen ratio and the Hydrogen to Carbon ratio are also shown. These graphs help identify trends and patterns that would not otherwise be obvious.

![CHN Comparison](image)

Figure 25 Comparison of Carbon, Nitrogen and Hydrogen levels

Nitrogen values across all the samples were consistent with the values proposed by various research sources, with Sample 9 being the exception. Sample 9 (red gum wood chips produced in a TLUD kiln) had a nitrogen weight of 0.11%, while Sample 3 (Leaves and twigs in a TLUD kiln) had the highest level of nitrogen with a value of 0.705%. While certain samples deviate from the mean, no obvious patterns appear with respect to feedstock or kiln type, as visible in Figures 28 and 29.

In order to get a better understanding of the significance of the Nitrogen in biochar, it has to be represented as a ratio of carbon content (Nguyen and Lehmann, 2009). The carbon to nitrogen ratio is an indicator of soil health and nutrient availability in the soil (Iqbal, Garcia-Perez and Flury, 2015). When organic matter decomposes in the soil with amendments, such as biochar, having a relatively low but substantial C:N ratio, nitrogen is temporarily released into the soil. The nitrogen is then available to the plants for mineralization (Shackley et al., n.d.), which aids plant growth. A high C:N ratio allows microorganisms in the soil to consume the mineralized nitrogen, thus stunting plant growth (Jassal et al., 2015). A review of the C:N ratios of the biochar samples generated during the course of this project would suggest that samples 4 and 8, both pea straw produced in a TLUD kiln and an earth kiln respectively, provide the best options in soil where mineralization is required to act as a soil conditioner. It is important to note that the carbonization of the feedstock during the production process artificially raises the level of carbon in the soil, thus increasing the C:N ratio. This would explain the high C:N ratios present in some biochar; the actual C:N ratio would be reliant on the amount of labile, or easily broken down, Carbon in the biochar.
An analysis of the Hydrogen levels in the samples provides some interesting results in the context of existing research. Research shows that an estimated range between 0.35% and 3.8% can be considered normal for levels of Hydrogen in biochar (Masek et al., 2013). While eight of the samples are firmly within that range, samples 4 and 8 (pea straw) are significantly higher than the rest. The presence of Hydrogen in biochar can be a useful indicator of soil stability. The ratio of Hydrogen to Carbon, or the H:C ratio, is indicative of a sample’s aromaticity - a property of an atom with stable molecular geometry. The H:C ratio is a proxy for the aromaticity of the sample, its ability to be mineralized in the soil, and consequently, the effect of the biochar on soil stability. The H:C ratio corresponds to the number of H=C bonds per carbon atom in the biochar, which is indicative of biochar stability in the soil (Ronnse et al., 2012). This is due to the relationship between number of H=C bonds, the subsequent size of the graphene clusters formed, and its impact on stability (Budai, Zimmerman and Cowie, 2013). Ultimately, the mechanisms by which biochar improves soil fertility are not fully understood. A compilation of research articles by the United States Department of Agriculture on the stability of biochar reveals that there is not much research, or current protocol for finding a proxy for microbial degradation in soil, mainly due to the fact that soil composition varies greatly depending on the geographical location (Spokas, 2010).
Figures 28 and 29 below show a comparison of the C:N ratio by both kiln and feedstock types. The grouping of results according to feedstock type, as made obvious by the colour coding, coupled with the lack of pattern when analyzing the kiln graph, indicates that the C:N ratio is dependent more on the feedstock type than the production method used. Even amongst the same feedstock type, the effect of the kiln appears to be non-existent on the C:N ratio of the sample. Both pea straw samples have the lowest C:N ratio, while both the red gum wood chips samples had the highest C:N ratio. A noticeable grouping of results is the fact that as the density of the feedstock increases, so does the C:N ratio. In this case, the ideal feedstock to use would be dependent on the intended use, but the pea straw appears to have the most positive effect on soil mineralization ability.
A general analysis of the H:C ratios above showed that pea straw as a feedstock had a significant effect on the biochar samples. Taking for certain that pea straw is by far the best feedstock in terms of H:C ratio allows us to omit samples 4 and 8 (Pea straw based biochar) and analyse any trends in the rest of the samples. Figures 30 and 31 below show a colour coded comparison of the rest of the samples by ordering them from lowest to highest and highlighting the different feedstocks and kilns. While the graphs below do not show any obvious trends or patterns with the data, an analysis of feedstock by kiln shows a pattern. The arrows on the graphs below highlight for one such sample (Red gum wood chips) that the Earth kiln variant is higher than TLUD kiln variant. This can be observed across all the samples; given the same feedstock, the Earth kiln produces biochar with a higher H:C ratio than the TLUD kiln equivalent.

A common theme across the CHN analysis of all the samples shows the effectiveness of pea straw as a feedstock. Pea straw has the highest H:C ratio across all samples, indicating the highest level of stability as biochar in the soil. It also has the lowest substantial C:N ratio amongst the samples, which allows it to be a great soil conditioner by encouraging nitrogen mineralization by plants in the soil. The low amount of Carbon present in the pea straw biochar, when coupled with the H:C and low C:N ratio, suggests that a greater extent of carbonization has taken place compared to the other samples. This subsequently implies that pea straw biochar has a greater amount of inorganic material in the ash. The connection between the ash and pH levels of pea straw, and the other samples, is investigated in the next section.
A.1.4 pH

The results derived from testing the pH of the biochar samples add information to an emerging trend. The two samples with the highest pH level were samples 4 and 8, both pea straw yet again. This could imply that the density of the samples has an effect on the pH levels of the samples. A notable trend in all the samples is that the pH is consistently alkaline. This is useful as a soil amendment tool to counteract acidic soil (Jindo et al., 2014). The pH level of samples is likely to be correlated with the presence of oxygen functional groups in the biochar; more oxygenated carbon is retained during a severe pyrolysis process, and consequently the acidic groups have become deprotonated resulting in more alkaline pH (Ronsse et al., 2012).

Referring to the earlier analysis of the samples, functional groups were also central to the absorption and water holding capacity of biochar. A comparison of the H:C ratio, central to the functional groups (as mentioned in the Absorption section of the discussion) to the pH levels should show that the samples with greater carbonization should have a more alkaline pH (Yargicoglu et al., 2015). Comparing the pH levels with the H:C ratio shows a generally negative trend; the H:C ratio is slightly smaller for biochar samples with a greater alkaline level. Interestingly, the two exceptions to this trend are samples 4 and 8 again. Both the pea straw samples have the highest alkaline level, as well as the highest H:C ratio. This would indicate that the pH levels in biochar is not a simple correlation to the functional groups. A possible explanation for these results comes from the burn times of the relative samples. The pea straw based biochar samples both had the shortest burn times to pyrolyse from feedstock to biochar and the low yields. The combination of both these factors could imply that samples 4 and 8 had a higher ash content as compared to the rest of the samples, and the higher level of ash contributed
to the higher alkalinity. Ash is a common lime alternative used to correct soil acidity, so it would follow that the biochar with high levels of ash would also have the higher alkalinity amongst the biochar samples (Ohno and Susan Erich, 1990).

A comparison of the samples organized by feedstock and kiln types is shown in Figures 34 and 35 above. There appears to be no connection between the pH levels and the kiln type used to make the biochar samples. With regards to the feedstock type, the samples containing pea straw have the two highest pH values whereas the red gum wood chips have the two lowest pH levels. This relates to the previous CHN analysis where it was shown that pH has a greater amount of inorganic material in the ash, and the earlier yield analysis that showed that pea straw provided the lowest yield (potentially implying that it had the highest ash content). And as discussed earlier, the alkalinity of the pea straw can be attributed to the high ash content in the biochar samples. A closer look at the graphs indicate that while the kiln type has no impact on overall biochar pH levels, TLUD kilns consistently produce biochar with higher pH than Earth kilns when the same feedstock is used. The arrows in Figures 34 and 35 above show one such relation, but can be applied to all the feedstock used in this data set; given the same feedstock, TLUD kilns produce biochar with greater alkalinity.
8.3 Summary

The results obtained during the testing phase of the project have been summarized in Table 8 below. The major characteristics, the effect they have on the soil, environment, and users, and what conditions they can be ideally used for are presented. The best type of feedstock to use, the ideal production method, as well as any alternatives needed in case of a lack of access or availability are also presented.

Table 8 Results Summary

<table>
<thead>
<tr>
<th>CHARACTERISTIC</th>
<th>EFFECT/IMPACT</th>
<th>BEST FEEDSTOCK TYPE</th>
<th>IDEAL PRODUCTION METHOD</th>
<th>IDEAL APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>YIELD</strong></td>
<td>Less feedstock used to produce maximum amount of biochar</td>
<td>If using a TLUD kiln, wood chips are most effective (red gum or pine)</td>
<td>Earth kiln for feedstock of low density or low feedstock volume</td>
<td>Maximising yield is an important characteristic when considering limited amount of resources available for use as feedstock</td>
</tr>
<tr>
<td></td>
<td>Improves efficiency</td>
<td>If using an Earth kiln, leaves and twigs are most effective</td>
<td>TLUD kiln for feedstock of high density</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Less intensive in terms of resources and cost</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>ABSORPTION</strong></td>
<td>Increased water retention in biochar</td>
<td>Pea straw is the ideal feedstock to use to maximize absorption.</td>
<td>No general ‘ideal’ production method. If pea straw is not available, using a TLUD kiln will produce more absorbent biochar</td>
<td>Ideal to use biochar with strong absorption characteristics in areas where the soil is dry or the land is generally arid to aid plant growth</td>
</tr>
<tr>
<td></td>
<td>Greater water holding capacity in soil</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Improved carbon sequestration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>C:N RATIO</strong></td>
<td>Improve soil nutrition by acting as a soil conditioner</td>
<td>Pea straw</td>
<td>No effect on biochar with respect to kiln type</td>
<td>Using biochar with a low, but substantial, C:N ratio (&lt;50) in soil lacking in nutrients, especially nitrogen will aid plant growth</td>
</tr>
<tr>
<td></td>
<td>Aid with nitrogen mineralization which aids plant growth</td>
<td>Correlation with feedstock density, so use less dense feedstock to improve chances of having lower C:N ratio</td>
<td>C:N ratio is a characteristic that is feedstock dependent at a molecular level</td>
<td></td>
</tr>
<tr>
<td><strong>H:C RATIO</strong></td>
<td>Improve stability of biochar in soil</td>
<td>Pea straw is clearly the most obvious choice for maximizing the H:C ratio of the biochar</td>
<td>No general ‘ideal’ production method. If pea straw is not available, using an Earth kiln will produce more stable biochar</td>
<td>Useful when planning a long term solution for soil amendment and carbon sequestration</td>
</tr>
<tr>
<td></td>
<td>Create long lasting biochar that will stay in soil for a long period of time</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>Neutralise soil with low pH levels</td>
<td>Pea straw produces biochar with the highest pH</td>
<td>No general ‘ideal’ production method. If pea straw is not available, using a TLUD kiln will produce more alkaline biochar</td>
<td>Ideal for use in conditions where the soil is acidic and hindering plant growth</td>
</tr>
<tr>
<td></td>
<td>Act as a soil conditioner to aid plant growth</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
8.4 A Humanitarian Approach

The main focus of this project has been to approach a developing technology from a humanitarian point of view. More specifically, the project aimed to apply the concept of appropriate technology, which generally refers to the application of technologies in small scale, energy efficient, and people-centred applications around the world. The push for sustainable development has been supported and encouraged by organisations such as Engineers Without Borders, the American Society of Mechanical Engineers, and even the United Nations in order to facilitate affordable and sustainable solutions to humanitarian challenges. The major distinction between this project and other research work conducted to test biochar is the application of the concepts of appropriate technology through the entire production process. From choosing the feedstock, to the manufacturing of the pyrolysing kilns, and even in the analysis of the test results, there has been an intended focus on asking the question “What impact will this have on the people who have the most use for it?” While the results achieved during this project can be easily achievable by existing technologies, the financial and environmental impact of these systems is seldom considered.

The first stage of the project involved researching and obtaining various feedstock types to be produced into biochar and tested. The two key components that encompass a humanitarian approach here are the feedstock types, and the materials and designs required to manufacture kilns for the production process. The importance of using readily available resources is evident in this approach, as the local members of an agricultural or rural community must have access to all the materials and skill they require to set up a self-sustaining, financially viable process to produce and use efficient biochar. The feedstock used for this project was obtained from local, usually free, and readily accessible materials. Trees from the local Adelaide hills were used as a source for most of the feedstock types used for the biochar production process. Foliage and branches from local trees are readily available for anyone living in an agricultural or rural environment, and cost nothing to use. Pea straw is also readily available for people living in farming communities. The feedstock used in this project have not been pre-treated or ‘improved’ from their original condition. Pre-treating a feedstock can help produce better biochar, but the added cost and complexity to the process can make it detrimental to the project approach of Appropriate Technology.

The importance of using readily available resources is also a key component in manufacturing the kilns required for the biochar production process. As seen in Figure 36, the highly functional, advanced design systems for biochar production can range from $900,000 to $55 million (Shackley et al., 2011). While the biochar these systems produce are highly efficient and have the best characteristics, such costs are unviable for a grassroots, agricultural or rural community. While the more expensive systems might ultimately provide biochar at a cheaper cost per ton, the accessibility and long term costs to the consumer would exceed that of a personal small biochar kiln. Although compromise between quality and costs have to be made, the results obtained from this project do not indicate that the biochar produced in the small, handmade kilns are vastly outmatched by the more expensive systems, proportional to their cost.

<table>
<thead>
<tr>
<th>Studies</th>
<th>Yearly feed (odt)</th>
<th>Total capital costs (US$m)</th>
<th>Yearly capital costs (20 yrs, 8% interest) (US$m)</th>
<th>Capital cost per odt feedstock (US$)</th>
<th>Total operating costs per odt feedstock (US$)</th>
<th>Ref.</th>
</tr>
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<td>Hinode, Tokyo</td>
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<td>55.5</td>
<td>5.66</td>
<td>22.2</td>
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<tr>
<td>McCrll et al.</td>
<td>70,080</td>
<td>14.2</td>
<td>1.45</td>
<td>20.7</td>
<td>31.6</td>
<td>[28]</td>
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<tr>
<td>Bridgewater et al. (2002)</td>
<td>17.05</td>
<td>1.739</td>
<td>15.4*</td>
<td>25.0</td>
<td></td>
<td>[7]</td>
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<tr>
<td>Bridgewater (2009) small-scale fast pyrolysis</td>
<td>2000</td>
<td>2.7</td>
<td>0.28</td>
<td>140</td>
<td>207</td>
<td>[5]</td>
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<tr>
<td>Bridgewater (2009) medium-scale fast pyrolysis</td>
<td>16,000</td>
<td>11.0</td>
<td>1.12</td>
<td>70</td>
<td>13.2*</td>
<td>[4]</td>
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<tr>
<td>Bridgewater (2009) large-scale fast pyrolysis</td>
<td>160,000</td>
<td>52</td>
<td>5.3</td>
<td>33.1</td>
<td>6.2*</td>
<td>[5]</td>
</tr>
<tr>
<td>Coaltec</td>
<td>12.53</td>
<td>10.2*</td>
<td></td>
<td></td>
<td></td>
<td>[29]</td>
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<tr>
<td>UKBRC large-scale</td>
<td>184,800</td>
<td>41.25</td>
<td>4.21</td>
<td>22.8</td>
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<tr>
<td>UKBRC medium-scale</td>
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<td>51</td>
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<tr>
<td>UKBRC small-scale</td>
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<td>0.9</td>
<td>0.092</td>
<td>46</td>
<td>54.5</td>
<td></td>
</tr>
</tbody>
</table>

Notes: US$/U exchange rate of 1.5.
1 The capital costs include both the pre-treatment and pyrolysis equipment except for the case of Bridgewater [5] and Coaltec [29];
2 That including pre-treatment;
3 The operational costs are calculated in Bridgewater (2009) as 13% of the yearly capital charge. Since the authors used a capital recovery factor of 16%, we have calculated the operational costs using that value rather than our value 10.2
c/3: Oven dry runs
UKBRC: UK Biochar Research Centre.

Figure 36 Table highlighting costs of biochar production systems Source: (Shackley et al., 2011)
This project investigated five different types of feedstock, the analysis of which can be found in the above section (8 – Discussion). The analysis has indicated that the best biochar for general use is produced using pea straw. While biochar is not a blanket solution to every soil amendment and carbon sequestration problem all around the world, pea straw would cover the broadest requirements for general use. Pea straw was tested as producing the best biochar in terms of absorption, H:C ratio, C:N ratio, and pH level. This would mean that biochar produced from pea straw would have the greatest benefit as a long term, carbon sequestration, and soil amendment option out of all the samples tested. As biochar can stay in the soil for periods ranging from decades to millennia, its use as a carbon sequestration tool is improved by its longevity in the soil (Nguyen and Lehmann, 2009). Additionally, improving nutrient mineralisation and the pH level of the soil is critical in the ability of biochar to act as a useful soil amendment option. While there might be other feedstock available that could produce more efficient biochar, the emphasis in this project was on sourcing feedstock from readily available, local sources to improve accessibility and reduce costs. The biochar samples produced for this project were a reflection on the locally available feedstock sources, which incidentally proves to be the greatest hurdle in compiling a general guide to biochar for global use. Relatively little is known about the mechanisms by which biochar improves soil fertility. This is mainly due to the variety in plants and trees from which biochar feedstock can be sourced, and the fact that soil can vary vastly from one region to the next. By making biochar accessible at a grass roots level, a “learn by doing” approach can be applied in gathering more information and hopefully increasing the knowledge base for biochar use.

Two main types of kilns, the Earth kiln and the TLUD kiln, were tested for this project – with a third kiln providing a single sample to add analysis for comparison. As mentioned with the preferred feedstock type, the choice of kiln used is dependent on multiple variables: cost, intended period of use, volume of biochar required, and personal safety. Most of the tests conducted to analyse the kiln types used showed a relative balance between the Earth kiln and the TLUD kiln. Depending on the use and the feedstock type, either kiln could be used to maximise efficiency and applicability. When considering the ideal production method for producing biochar, and when the characteristics cannot separate the two, other factors must be taken into account. Smoke inhalation and its consequent health effects are currently felt by the approximately three billion people around the world who rely on the burning of solid fuels for their energy usage (WHO, 2014). An open Earth kiln would add to the problem, as the main mechanism by which biochar is produced in an Earth kiln is through hand fed feedstock in a pyrolysing open pit. Biochar is used both as a soil amendment tool, and a carbon sequestration tool. An open flame emitting a high volume of carbon dioxide into the atmosphere during the biochar production process would result in a carbon neutral, or even a carbon negative, net outcome (Biochar-international.org, 2016). In situations where the biochar must be produced close to the source, or the tools and resources required to build a kiln are not available, an Earth kiln is more practical. All things considered however, a TLUD kiln would be a more viable option in terms of efficiency, safety, and effect on biochar characteristics. Although the kilns used in this project are not as effective as more expensive, industrial systems for producing biochar, the results are indicative of having similar characteristics albeit not at the same level of quality.

Figures 37 and 38 show equipment used to produce biochar that has been compared with the biochar produced for this project at multiple times in Section 8 – Discussion. These systems are indicative of commercial systems available in the market to produce biochar. While these machines are highly optimised and carefully designed to produce optimised biochar, such technology is not a viable option to the millions of people living in rural, agricultural, and sometimes impoverished communities.

Figure 37 Commercial biochar production system (Ronsse et al., 2012)
Systems such as the ones shown in Figures 37 and 38 include features that allow for pre-treatment of the feedstock, post treatment of the biochar, and collection of by-products to optimise the production process. Commercially, feedstock is rarely fed directly into a kiln or reactor without extensive pre-treatment (Cummer, 2002). Mechanisms to dry the feedstock and reduce the particle size are used in complex systems to increase the yield of biochar, as well as the yield of any by-products such as bio oil and syngas. Such systems are not feasible in remote agricultural communities, especially when cost is a key factor in the decision making process. Such commercial and large scale biochar production systems can range anywhere from thousands to millions of dollars. The TLUD kilns used in this project were all hand manufactured and cost approximately $60 AUD. The resources and complexity of design exhibited by the commercial systems are beyond the means of most of the world’s population; the TLUD kilns used in this project were made using old oil drums, scrap metal, and some basic power tools. While the biochar produced by these kilns are not as effective as the biochar produced in the more expensive systems, achieving 30% – 50% of the expected results for a fraction of the cost would indicate a good return.

In taking a humanitarian approach to this project, the focus was placed primarily on the people living in impoverished, agricultural communities with limited access to money and resources. As these are the people who ultimately have the greatest need for biochar and its uses in improving agricultural and environmental conditions. While expensive and complex systems are not detrimental to the cause, providing easy access to simple designs and straightforward concepts are a key component in expanding the knowledge and use of biochar worldwide.

Figure 38 Commercial biochar production system (Masek et al., 2013)
9 Conclusions

Research conducted into the field of biochar use showed that it has the potential to be essential in addressing the growing food needs for an ever increasing population, while also acting as an important tool in successfully sequestering carbon dioxide in soil. The increase in population predicted to occur over the next 40 years will result in an increase in the global demand for food. The steady depletion of natural resources, coupled with a need to curb the environmental effects of the food supply system, will affect the ability to produce food in the future. The effects of these issues, and the need to counteract the negative effects of climate change, require a need to improve the efficiency of food production. Biochar has been found to have qualities that improve soil fertility and sequester carbon dioxide in the soil. Created when charcoal is produced through the heating of biomass in the absence of oxygen, the use of biochar will allow for greater plant yields while allowing for a reduction in the levels of greenhouse gases through the soil carbon sequestration.

This project was designed to investigate the gaps in the existing field of research in biochar production and effectiveness, while approaching the project from a humanitarian point of view, and with an emphasis on the concept of ‘Appropriate Technology’. The intention was to improve the general quality of life for the intended end users, while maximising the efficiency of the biochar which would assist in boosting crop yields. Project goals were outlined and testing methodologies were planned in order to effectively produce biochar and compare a set of characteristics deemed relevant through research. Experimental tests for characteristics such as pH levels, absorption, and elemental composition were designed for the purpose of testing and analysis of biochar samples produced using five types of locally sourced, readily available feedstock and two main types of kilns (Earth kiln and TLUD kiln). The results were summarised and then discussed in depth with relevance to the effectiveness of the characteristics displayed by the biochar as a soil amendment and carbon sequestration tool. The results found that the best feedstock type for general use was pea straw, and the ideal production method was through the use of a TLUD kiln. Due to the nuances of producing biochar specific to the regional and personal requirements, the feedstock and kiln type deemed to be ideal are not universally applicable. The effectiveness of various types of feedstock and kilns in the context of how the characteristics are applicable to certain soil conditions were also mentioned in the results summary.

Finally, biochar and biochar production technology was discussed from a humanitarian point of view. While complex designs and expensive commercial machines can be used to optimise biochar production and characteristics, even more significance must be placed on making the technology available to people living in impoverished or remote agricultural communities. There is still much to be learned about the mechanisms of biochar as a soil amendment tool. Designing biochar as an appropriate technology for the people living in agricultural and impoverished communities would not only greatly help millions of livelihoods and improve quality of life, it would also help improve general understanding of the effects and impact of biochar as a highly diverse and versatile tool in solving some of the most pressing issues facing the world today.

9.1 Future Work

The mechanisms by which biochar improves soil fertility are not fully understood. This implies great scope for the investigation of biochar as a soil amendment and carbon sequestration in a broad context. The feedstock tested for this project were obtained from local and readily available sources, and due to the scope of the project, were limited to only five types. A comprehensive analysis could include the effect of any number of feedstock types on biochar characteristics. Only two kilns were properly analysed during this project, with a third kiln providing feedstock for a partial analysis. More kiln types, and more variants of the kiln types used in this project, can be tested to observe the effects on biochar characteristics.

With respect to characteristics, the absorption tests conducted for this project can be expanded upon. Instead of a single measurement, data can be collected for the absorption capabilities of biochar over multiple time periods. The results can then be graphed to show trends in biochar absorption capabilities and compared to biochar stability to indicate long term effects and impact on the soil. The following tests can also be run on the biochar samples; some of these tests were considered at an early stage but then discarded as they were beyond both the scope, and the financial constraints of this project.

1. Ash within the biochar sample
2. Volatile organic content
3. Adsorption
4. Surface area
5. Porosity
6. Cation Exchange Capacity

The highly versatile nature of biochar allows for testing to be done on a great variety of features and aspects of the technology, which will hopefully shed more light on biochar and its usefulness to the environment.
10 References


Brewer, CE., Brown, RC. (2012). 5.18 Biochar, Iowa State University, Elsevier Ltd, 357-384


Karhu, K., Mattila, T., Bergstrom, I., & Regina, K. (2011). Biochar addition to agricultural soil increased CH4 uptake and water holding capacity - Results from a short-term pilot field study. Agriculture Ecosystems & Environment, 140(1-2), 309-313.


Appendix A  Gantt Chart

[Detailed Gantt Chart with task names, start and end dates, and progress indicators]
Appendix B  CHN ANALYSIS RAW DATA

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<th>Nitrogen</th>
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