APPLICATION OF BIOCHAR FOR CARBON SEQUESTRATION MITIGATING IMPACTS OF CLIMATE CHANGE: AN ANALYSIS OF DETENTION BASINS IN FARGO, NORTH DAKOTA

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The Supervisory Committee certifies that this ***disquisition*** complies with North Dakota State University's regulations and meets the accepted standards for the degree of

MASTER OF SCIENCE

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ABSTRACT

Biochar can be used for many purposes beyond its use for carbon sequestration and is a multifunctional substance. Detention basins are primarily a one-use area utilizing large spaces to hold stormwater, allowing the production of biomass for biochar would allow many uses from the space. Analysis of biochar application in detention basins as a means of utilizing space for maximum benefits. Additionally, helping with mitigation of climate change as well as increased rates of infiltration. In a world where climate change is at the forefront of importance, it is time now, more than ever, to put focus on change to better the world for future generations. In this paper, you will see an introduction of the importance of researching biochar, a literature review of research found on biochar, a feasibility study using an example site, and concluding points.

ACKNOWLEDGMENTS

My graduate education has been one of the most rewarding and fulfilling experiences of my life. However, I know it came from the support and love of those around me and the accomplishments were only possible because of the wonderful people in my life. I would like to thank my Uncle Neil who passed in 2019, who pushed me to continue my education. I would like to thank my parents for supporting me and helping me when needed, it has meant the world to me. I would like to thank my grandparents for showing me the value of persistence. I would like to thank my father-in-law for his love of science and our enlightening conversations. I would like to thank my children, Augustus and Westley who have given me strength and reason for continuing my education, you both made every single minute of it worthwhile. I would additionally like to thank my husband for his utmost patience, love, and understanding as he has been the most supportive partner I could have asked for as I continued my education.

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DEDICATION

This paper is dedicated to my grandmother Valoie Olson for being a fierce woman in my life and being a strong advocate for my education.

"Strong women

May we know them

May we be them

May we raise them"

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1. INTRODUCTION

As populations rise and our resources are depleted, there is a drastic need to protect and sustain nonrenewable resources as well as renewables to protect the future of life as we know it. Wildfires, droughts, and other extreme weather events are becoming more frequent (Intergovernmental Panel on Climate Change (IPCC), 2021). The leading cause is human's acceleration of climate change which has led to an excess of carbon in our atmosphere. Restoring the natural balance and finding a means for carbon sequestration to remove atmospheric carbon is a necessary component in slowing/reversing climate change impacts (IPCC, 2021).

Climate change has become one of the largest threats to our health and survival (IPCC, 2021). Addressing concerns of implications and symptoms of climate change become more apparent each day. We need to start taking transformational measures to ensure we are not exceeding an increase of temperature of our planet that leaves worse conditions for our children. Biochar is one system which can help restore the balance of carbon by stabilizing it in a charcoal form (IPCC, 2014). Biochar is a charcoal form of carbon that is created by heating biomass without oxygen to produce a carbon rich product of biochar (IPCC, 2014). The information surrounding biochar is not new, however, my goal is writing this paper to show how easily it can be done without emitting any carbon in the process.

1.1. Statement of the Problem

Current measures being taken for climate change mitigation do not address a stable carbon storage (Krier, 2012). Additionally, there is a need to continue researching all solutions available and adapt accordingly with our ever-changing environment. Biochar's potential has long been researched both as a soil amendment and a potential resource for the fight against climate change (IPCC, 2014). Research has primarily focused on agricultural lands as a storage for carbon, which has recently changed as agriculture lands have high disturbances that impact the stability of carbon (Popkin, 2021). Many organizations hoping to invest in carbon tax initiatives are wanting to see a stable source of carbon being held. My reviews will show a method for which it is possible to produce biochar without releasing any additional carbon. My writings will also show a comparison between forested systems and grassland systems and the stability between the two for carbon sequestration potential. It will also provide options for biochar use all of which are maximizing carbon negative potential.

1.2. Purpose of Research

The purpose of this research is to show there are feasible options which can be implemented immediately to try and mitigate climate change. Many options being researched are expensive and/or take years to see results (Berwyn, 2020). The purpose of this paper is to show there is an option which is not only affordable but can also create results in a much shorter time.

I hope my research can provide a guide which is universal to helping with climate change initiatives. The goal is to provide a layout that can be implemented anywhere with little change. It also showcases biochar's important role in climate change and why it may be a better and more sustainable option than forested systems.

Transforming mowed green spaces into a vast array of diverse forbs and grasses will help not only with carbon sequestration (Unkefer et al., 2001), but also provide habitat for many species including pollinators by restoring native habitat (Filazzola et al., 2019). The research will lay out how to use stormwater detention basins as a multiuse space instead of a single use space that will additionally require less maintenance than mowing.

A detention basin is an area which has been excavated for stormwater runoff. Unlike a retention basin that holds water, a detention basin only temporary holds water. Primarily the focus of basins is to manage stormwater for flood protection and use for irrigation (Teschemacher et al., 2020). Basins were selected for this project given the importance they play in urban areas, the magnitude of land they cover, and the importance of promoting biodiversity in urban areas as well as promoting a multiuse site.

Biochar is unique as one of the few systems offering a carbon negative solution to climate change instead of just being carbon neutral (Glaser et al., 2009). With trending rates of climate change acceleration, it may not be enough to try and reduce emissions through neutral systems, we may need to go above and beyond and use solutions such as biochar that offers a carbon negative solution.

1.3. Problems of Interest

i. How much carbon can a per hectare basin sequester in comparison to mowed turf grass?

ii. How do we feasibly produce and harvest biochar without adding to our carbon footprint?

iii. How do forested systems sequester carbon and how does it compare to grasslands?

iv. What does a feasibility site look like?

v. How do we calculate carbon credits for biochar?

vi. What can biochar be used for?

vii. What biochar application options are best for maximizing carbon negative benefits?

Primarily, research was focused on detention basins in Fargo/Moorhead, however, changes to plant species can be done to implement plans in other regions. All new built environment developments must have a detention or retention basin as the city of Fargo, North Dakota will not be expanding its storm water infrastructure for any new developments (Nicole Crutchfield, Fargo City Planner, Personal Communication). This means that any new facility will have to implement their own storm water mitigation which increases the magnitude and frequency of basins. Each detention basin site will have a similar outcome, but with their own unique native species. The plans outline here are not limited to basins; however, they are an example of turning a single use space into a multiuse space and restoring habitat in urban areas. Urban areas have long needed sustainable solutions to add habitat back for pollinators as well as other species (Monroe, 2016).

The paper will additionally consist of a literature review covering climate change implications, an introduction to biochar, seed mixes that are allotted for use in basins in Fargo, North Dakota, importance of carbon sequestration in grasslands, an analysis of how forested systems compare for carbon sequestration, and carbon credits as they apply to biochar application. The final chapter will consist of a feasibility study using an example site to provide information on the applicability of producing biochar on a basin. This includes costs and benefits associated with the example proposed project. Lastly, the paper will finish with a conclusion of my findings.

2. LITERATURE REVIEW

2.1. Climate Change

The climate is in a constant state of change. However, much of the changes have been accelerated by human caused activity. There have been many changes to atmospheric abundance of greenhouse gases and aerosols (IPCC, 2014), leading to a change in solar radiation and land properties which in turn changes energy in our climate system. Globally, rates of carbon dioxide, methane and nitrous oxide have increased because of humans since 1750 which greatly exceed values found in pre-industrial periods as observed in ice cores examined from thousands of years ago. The primary reason for an increase in carbon dioxide is fossil fuel and changes in land-use. However, the rise in methane and nitrous oxide is highly tied to agriculture (IPCC, 2014).

The most important greenhouse gas in the anthropogenic era is carbon dioxide (IPCC, 2014). Carbon dioxide has risen globally since the pre-industrial area from around 280 ppm to 379 ppm. It has consistently been increasing over time. During the ten-year period from (1995-2005), carbon dioxide acceleration has been at its highest at a rate of 1.9 ppm per year. Since the beginning of atmospheric measurements (1960-2005) the average has been 1.4 ppm per year. Fossil fuel is the primary culprit of increased atmospheric carbon dioxide. Fossil fuels carbon dioxide emissions increased annually to around 6.4 GtC in 1990s to 7.2 GtC per year throughout 2000-2005 (IPCC, 2014).

Direct observations of climate change are observed with our warming climate system (IPCC, 2014). It has been measured through an increase of global air and ocean temperatures, melting of snow and ice, and global rising sea levels. Between 1995-2006 eleven out of twelve years were ranked among the warmest years ever recorded since 1850. Temperature increases from 1850-1899 to 2001-2005 is 0.76 degrees Celsius. Local influences such as urban heat islands exist but are minuscule and only equate to less than 0.006 degrees Celsius per decade over land and have zero impacts over ocean values (IPCC, 2014).

There have been many long-term changes in climate that have led to recordable changes from Anthropocene activity (IPCC, 2014). Including but not limited to:

- Artic temperatures averaging double what they were in past 100 years.
- Artic sea has shrunk by 2.7% per decade since 1978, with larger periods of 7.4% in the summer per decade.
- Permafrost layers have temperatures above it which have increased 3 degrees Celsius from 1980. Artic seasonally frozen ground has seen a 7% decrease since 1900 with up to 15% in some areas in the spring.
- Increased precipitation in North and South America, northern Europe, and northern and central Asia. Meanwhile, drying has been observed in Sahel, the Mediterranean, southern Africa, and parts of Asia. Although, long term trends have not been observed in large regions.
- Continued changes in precipitation and evaporation in oceanic systems are freshened of mid and high latitude waters mixed with increased salinity in low latitude waters.
- Mid-latitude westerly winds have been increasing since 1960.
- Longer drought periods as well as accelerated intensity of droughts seen since the 1970s, mostly observed in tropical and subtropical regions. Increased drying mixed with higher temperatures and a decline in precipitation have caused severe drought periods.
- Land areas are seeing more heavy and frequent precipitation with warming temperatures which includes an increase in atmospheric water vapor.

- Heat waves, hot days, and hot nights have become much more frequent over the last 50 years.
- Evidence showing increases in tropical cyclone activity in North Atlantic since 1970 that directly relates to an increase in temperatures.

2.2. Introduction to Biochar

Biochar is a charcoal form of carbon which is slow to break down (Renner, 2007). Biochar is produced by heating biomass with no oxygen to form biochar (Schmidt et al., 2018). Biochar primarily has been used for soil health and fertility by increasing microbe activity in the soil. In recent years, an emphasis has been focused on biochar's potential for mitigating global warming and its importance on soil restoration (Conte et al., 2016).

Plants use photosynthesis and the process produces carbonaceous plant metabolites, it is then processed back to CO_2, when plants decompose (Conte et al., 2016). If plants are harvested and processed into biochar, there is up to a 60% reduction of carbon released. The charcoal form of carbon (biochar) is incredibly slow to release carbon in comparison to plant material left to decompose. This process reduces the amount of atmospheric CO_2 by disrupting the chance for decomposition (Conte et al., 2016). Figure 2.1 posted below, is an illustration of the biochar cycle. In addition, Figure 2.2 represents the process of producing biochar.

Figure 2.1: Depiction of Carbon Sequestration
Source: Adapted from Lehmann and Joseph, 2015

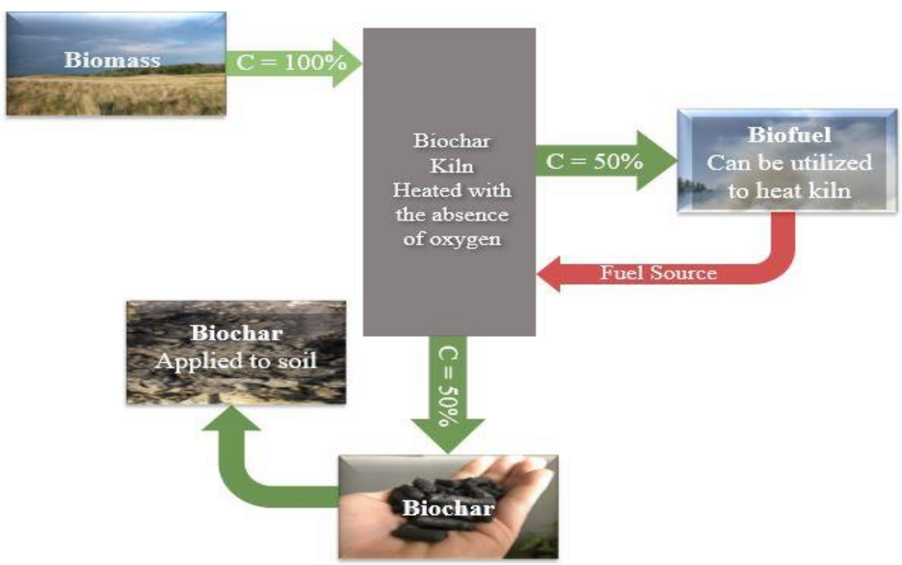

Figure 2.2: Depiction of Biochar Production
Source: Adapted from Lehmann and Joseph, 2021

Biochar is different from other charcoals in which the process of creating it uses no oxygen (Lehmann & Joseph, 2015). This difference creates a carbon rich biochar. Biochar is composed of aromatic compounds which are seen in rings of six carbon atoms linked together without oxygen or hydrogen which are typically seen in living organic matter as seen below in Figure 2.3. Perfectly aligned sheets of this are known as graphite. However, under temperatures used for making biochar, graphite is not formed, instead it is irregular arrangements of carbon containing oxygen, hydrogen and some minerals depending on the composition of feedstock (Lehmann & Joseph, 2015).

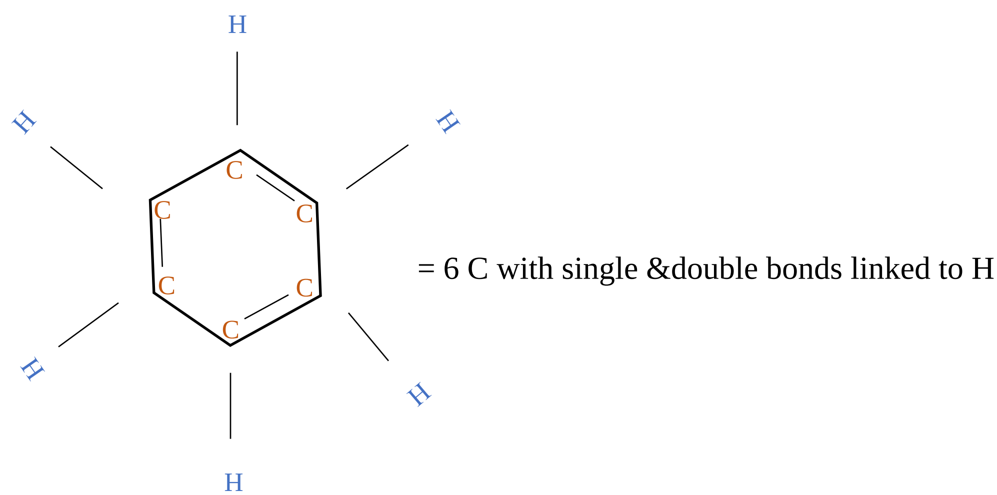

Figure 2.3: Aromatic compound seen with rings of 6 carbon and linked to hydrogen containing single and double bonds.

The molecular structure of biochar has both surface area and porosity (Lehmann & Joseph, 2015). Carbonaceous soils such as coal, charcoal, etc. contain crystalline particles composed of “graphite-like” layers which are organized turbostratically. Turbostratical layers are layers that are not aligned. Biochar is amorphus but does contain sections of highly conjugated aromatic compounds that form crystalline structures. Biomass processed with pyrolysis enlarges crystallites and increases their structure. Additionally, non-graphic carbon is changed into graphitic carbon in the pyrolysis process (Lehmann & Joseph, 2015).

Biochar’s stability plays an important role for its carbon sequestration potential (Yang et al., 2018). Stability is dependent on biochar’s ability to avoid oxidation. Biochar’s ability to resist oxidation is directly linked to its carbon sequestration potential. Carbon remains stable in biochar from endogenous minerals which protect it from chemical oxidation. However, biochar rich or fortified with iron are less stable and decomposes quicker. To promote the highest stability of biochar, there is a need to increase endogenous minerals which promote higher stability. Biochar provides a more stable solution than biomass. Although there is still a chance that biochar can decompose in soils, it is worth noting that biochar decomposes at a much slower rate with soils that have a clay content of 40-70%. Biochar's stability has been measured by using a calorimeter for thermogravimetry/derivative thermogravimetry and by using differential scanning calorimetry (Yang et al., 2018). These measures help us better understand the oxidation resistance of biochar.

Biochar production produces additional byproducts such as bio-oil and biogas. The maximum oil yield from a wheat straw pyrolysis study was 37.6% which was obtained using high pressure at 40 psi (Mahinpey et al., 2009). Higher psi and temperatures have a direct correlation to an increase of bio-oil over biogas. At 10 and 20 psi, gas yield was 57%, as pressure rose, bio-oil production increased, and gas yield decreased. Differences in temperature and pressure play a role in the outcome of biochar/bio-oil/biogas ratios (Mahinpey et al., 2009). Bio-oil's primary use has been as a biofuel which is a fuel source that is made from biomass instead of slow geological processes (Oasmaa et al., 2009).

The Intergovernmental Panel on Climate Change (IPCC) has listed biochar as an important carbon negative option (IPCC, 2021). Carbon negative is a process which reduces CO_2 instead of just offsetting it. Most processes today such as green energy (solar/wind) are carbon neutral which means they are not producing excess CO_2; however, they are not sequestering any either. This important factor is one of the reasons biochar stands apart from other climate change initiatives (IPCC, 2021).

In addition to carbon sequestration, biochar is beneficial for soil health and fertility. In short, biochar helps with water retention, ion exchange capacity, soil pH, nutrient availability, and biological activity (Lone et al., 2015). All these items add a balance back to soil health and is reparative to many years of damage. It also promotes better crop production and has a direct impact on higher yields for agriculture which has been its primary use and center of most research surrounding biochar production (Lone et al., 2015).

2.3. Limitations

This review contains limitations as it is not a comprehensive overview of biochar's use as a soil amendment. It is worth noting biochar can play a role in soil health and fertility and has long been used in agriculture (Schmidt et al., 2019). Biochar is used in agricultural practices by increasing soil pH, moisture content, nutrient retention, and increasing crop yield (Schmidt et al., 2019). Agricultural practices contribute to a large amount of greenhouse gas emissions (Krishnakumar et. al., 2014). Much of which is a loss of nutrients, little to no cover crops, and a depletion of carbon from the soil (McLauchlan, 2006). Global change has been fueled by agriculture both through crop production as well as livestock. Agriculture leads to disturbances of the land including tilling, fertilizing, and altering biomass which changes the balances of carbon, nitrogen, and phosphorus. Tilling can decrease organic matter by erosion loss, and it can degrade organic matter physically and biochemically which leads to an instability of organic matter. Biochar is an additive can help promote organic matter and can last for centuries if not longer, though much of this depends on the management of lands after application. Biochar promotes a balance with organic matter and restores soil carbon, which is helpful for ecological restorations as well as agroecosystems and an important tool for stressed agricultural lands (McLauchlan, 2006).

Biochar plays a role in prairie restorations as well. Given that biochar is a rich carbon it can help with the growth of many plant species including those common to the Midwest region such as native perennial grass, big bluestem *Andropogon gerdardii* (Adams et. al., 2013). However, research regarding prairies is limited because of the lack of economic benefits associated with prairie restorations. It is easy to see the impact from crop growth in a monetary value that is not seen as well in ecological application for habitat restoration. Promoting soil health and fertility is incredibly important in restoring damaged soils to be able to restore prairies sustainably and successfully (Adams et al., 2013). In addition, ecological restorations for prairies and grasslands, plays a critical role in the effectiveness of carbon sequestration as opposed to agriculture. As mentioned, agriculture practices typically disrupt the soil and therefore it can lose some of its carbon sequestration potential. Whereas with prairie and grassland restorations, the land is less impacted by tillage and other practices and any loss of biochar's carbon sequestration potential is minimized (Popkin, 2021).

Nevertheless, biochar plays an important role in agriculture. Agricultural soils can degrade from a reduction in nutrients and additionally an accumulation of pesticide residue (Yang et al., 2017). Biochar can provide a relief to some of those pressures which can lead to better crop yields as well as a reduction in stress from pesticide use. There is a high surface area in biochar which helps with cation exchange capacity and has a high stability (Yang et al., 2017). Biochar's high surface area allows for improved water holding, increased soil fertility, and adds to organic matter (Hue, 2020). Biochar can additionally help with an increase with microbial activity and diversity as well as helping in acidic soils or soils that are highly weathered (Hue, 2020).

2.4. Biochar Uses

There are a multitude of uses for biochar after the production of the product. With recent research, we now know it may not be the best solution to bury it in agriculture lands or other areas such as those highly disturbed as it lessens stability of sequestered carbon (Ofiti et al., 2021). Instead, it might be better to focus on areas with anaerobic conditions such as wetlands and peat bogs where biochar can be stored. These unique areas will slow down decomposition and better guarantee stability of biochar (Gupta et al., 2016).

Rising global temperatures have impacted the composition of soil organic matter (Ofiti et al., 2021). The IPCC models have predicted a 4.5 degrees Celsius increase in subsoil temperatures by 2100. These rising temperatures both atmospheric and surface-soil may impact the decomposition of soil organic matter and microbial communities. There are many uncertainties to how microbial biomass, soil organic matter, and carbon cycles may react under changing conditions and warming temperatures. These uncertainties can cause a reduction in stability of biochar in soil (Ofiti et al., 2021).

Using biochar in constructed wetlands can combine both the filtration potential of biochar as well as the carbon reduction potentially offers solution that has multiple benefits (Gupta et al., 2016). Gupta et al. conducted a study using different methods of filtration for constructed wetlands. Biochar was more efficient at reducing pollutants than wetlands that were composed of just gravel. In one of the wetlands (Wetland C), there was a 58.27% removal of nitrogen, 79.5% removal of phosphate, 68.1% removal of PO_{4}-P, 92.1% removal of NO_{3}-N, 58.3% removal of NH_{3}-N, and 91.3% of COD removal. There are many variables that can factor into the rate of pollutant removal such as infiltration, amount of precipitation, sediments, microbial activity, and plant absorption (Gupta et al., 2016).

Aside from anerobic application, biochar has another important use for water treatment. Biochar provides an effective filter for organic, inorganic, and microbial contaminants (Gwenzi et al., 2017). Evidence shows that activated biochar has the potential to filter out pathogenic organisms and heavy metals as well such as fluoride, phosphate, and nitrate. Many contaminants can be removed using biochar in an aqueous solution which is beneficial to water management. Biochar is relatively cheap to make in comparison with other water treatment methods and can be readily available most places which makes it a viable resource for developing countries (Gwenzi et al., 2017).

Biochar can be utilized for water filtration before being used as a soil amendment (Gwenzi et al., 2017) or in wetland restorations. Once it has been used for the purpose of drinking water treatment or wastewater treatment, biochar can then be used as an amendment for additional carbon sequestration, soil health, or used for agricultural purposes. However, there are limits to carbon sequestration on agriculture lands with frequent disturbances to soil (Popkin, 2021).

2.5. Anerobic Environments

Carbon dioxide (CO_2) can be sequestered in wetland ecosystems (Mitsch et al., 2013). However, wetlands, though a natural solution for sequestration, are also a natural source of greenhouse gases, primarily methane (CH_4). Carbon sequestration rates of wetlands override CH_4 emissions as most wetlands become a carbon and radiative sink. Wetlands annually sink around 830,000,000 metric tons per year of net carbon, even though they only make up roughly five to eight percent of terrestrial lands. Wetlands can provide carbon sequestration services even in created and restored systems. Though there is methane production, most wetlands are still considered net radiative sinks which allows the creation and restoration of wetlands to be of little concern for climate warming implications (Mitsch et al., 2013).

Wetlands have a slower decomposition rate because of anerobic conditions (Fennessy et al. 2008). However, decomposition rates of created wetlands and naturally occurring wetlands can vary. Decomposition rates are higher in natural wetlands as well as biomass production. This leads to higher concentrations of organic carbon, nitrogen, and phosphorus in the soil. Created wetlands tend to have less biomass, less nutrients, and a slower rate of decomposition (Fennessy et al. 2008). However, a slower rate of decomposition may be an asset for the carbon sequestration potential of biochar.

Biochar has been listed as a soil amendment for CH_4 capture (Zhang et al., 2019). Although biochar can provide a growth of aerobic methanotrophs which oxidates CH_4, studies have shown that biochar can have a chemical reaction that can stimulate anerobic oxidation of CH_4, by anaerobic methanotrophic archaea which is a possible mitigation of $CH_{4,}$ from a biochar application in anaerobic conditions. Methane is oxidized by adding biochar as the sole electron acceptor in anaerobic conditions (Zhang et al., 2019). More research is needed on the potential of carbon sequestration and stability of biochar in anerobic environments.

2.6. Importance of Carbon Sequestration in Grasslands

Although many ecological systems can be used for carbon sequestration, grasslands are uniquely different. Native grasslands have extensive root systems that can grow downwards of three meters deep or more. This is exceptionally true of native prairie species which harbor more carbon because of deep rooted plants than those of non-native species (Dietzel et al., 2017).

The averages in Table 2.1 can change with differences such as seed mix, age, and soil composition of a specific site (Yang et al., 2019). Although switch grass may hold a higher sequestration potential, it is important to look at all goals and objectives. If the only goal is to sequester carbon, switchgrass with little to no biodiversity, may be a solution. If the goal is to also promote habitat and biodiversity, there is a need to promote more species. Additionally, biodiversity promotes stability and resilience within a site (Yang et al., 2019). Each project will need to modify its vegetation to meet specific goals and objectives for a project. Switchgrass holds higher promise for CO_2 reduction per hectare, however, a lack of diversity may impact ecological services. Table 2.1 below shows the difference between switchgrass and native prairie with mixed diversity for carbon sequestration.

Table 2.1: Vegetation Comparison of CO2 Sequestration

Type of vegetation	Metric ton CO_2/hectare/year
Switchgrass[a]	4.45-11.61
Native prairie (mixed diversity) [b]	4.2

[a] Michigan State University, 2011
[b] Midewin Tallgrass Prairie, 2011

Typically, when we think of carbon sequestration, we look at forested systems. However, trees store their carbon in their above ground system. Whereas grassland species store their carbon in the deeply rooted systems. Part of the carbon storage is in the form of organic compounds from decomposing roots. The bulk of living roots have a lifetime of only a few years. This means if a disturbance occurs it is likely that a tree will release carbon into the atmosphere whereas a grassland will hold carbon below the soil surface where there is greater protection (Schahczenski & Hill, 2009).

In addition, utilizing otherwise mowed green space greatly cuts down on a carbon footprint. Mowing reduces root biomass which plays a large role in sequestering carbon (Kitchen et al., 2009). Continuous mowing impacts the quality of roots and their distribution which impacts soil carbon by distributing roots in shallower areas. It is estimated that around 7,257,478-18,597,287.2 metric tons of CO_2 is emitted every year from lawn mowers alone. (Hitchler, 2018). According to an EPA study, one lawn mower (gas powered) emits 0.04 metric tons of carbon and an additional 0.015 metric tons of other pollutants annually (Hitchler, 2018).

2.7. Biochar Market and Carbon Credits

Biochar carbon credits fall into the category of permanent sequestration of carbon (Steiner, 2008) Additionally, it is a form of carbon negative verses neutral methods. These differences allow biochar to be a sustainable solution for climate change and promotes the uniqueness of biochar verses other methods that may not be a permanent solution nor a negative reduction of carbon.

Biochar currently has been on the market mainly as a soil amendment. The price of utilizing it as a soil amendment has its limitations when it comes to feasibility based on price. The price of biochar is directly related to its demand as well as limited supply (Vochozka et al., 2016). The market for biochar is not well established making it more expensive because of its exclusivity. Biochar is recommended at no more than 25 metric tons per hectare (Bista et al., 2019). Additional biochar can be applied, however, there is a limit to the benefits associated with biochar and best use practices suggests around 25 metric tons per hectare to maximize benefits as well as costs. Biochar costs around $350 per ton and application for biochar is around $8 per ton (Sorensen & Lamb, 2018). On average, this equates to around $8,950 per hectare of application.

The social cost of carbon from integrated assessment models with varied assumptions estimates on the low end of $41.94 per metric ton of C, median level $137.26 per metric ton of C, and high end is $400.33 per metric ton of C (Hungate et al., 2017). The primary use of biochar to date has been as a soil amendment and the importance and valuation of biochar for agriculture use differs from that of carbon sequestration. However, recently focus has been put on carbon sequestration as a potential for biochar in addition to soil health (Galinato et al. 2011).

The estimated fixed carbon content of produced biochar is the basis for the GHG calculation. The value is from the mass of biochar, it's carbon content and the decay rate of fixed carbon in biochar taken from over 100+ year period (Etter et al., 2021). Organic carbon content of biochar (F_{Cp}) is related directly to feedstock and heating temperatures. For herbaceous material, it has a value of 0.65 ± 45% of Fcp for pyrolysis production. The following formula comes from the IPCC Method for Estimating the Change in Mineral Soil Organic Carbon Stocks from Biochar Amendments: Basis for Future Methodological Development and includes the fraction of biochar carbon remaining after 100 years.

$$CC_{y,t,}=M_{y,t}*F_{Cp}*PR_{de}$$

Where (Etter et al., 2021):

$CC_{y,t,}$ - Fixed carbon content for year x based on feedstock and application type of biochar

$M_{y,t}$ - Mass of biochar applied to year x (in tonnes)

F_{Cp} - Organic carbon content of biochar for the specified production type per tonne of biochar

- Value for fixed carbon content should be determined in a laboratory, however, low technology production facilities can utilize values found in IPCC for different feedstocks and production types
- Value for herbaceous vegetation pyrolysis is 0.65 +/- 45%

PR_{de} - Permanence adjustment from decay of biochar in soils (can be taken from literature, but is dependent on the system in which the biochar is applied to)

Emissions associated with the production of application of biochar can have an impact on the overall importance of emission removal (Etter et al., 2021). The equation for determining emissions for application state is below. At the application stage, there are no carbon removals or emissions considered since there was no biochar produced. If energy is renewable $E_{p,y}$ it is not considered and the value defaults to zero. Given the energy is a renewable source, for the feasibility study in this document $E_{p,y}$ defaults to zero. E_{ap} referes to emissions from biochar application in soil. Emissions resulting from fossil fuel combustion and fertilizer application are considered negligible for the feasibility study, therefore E_{ap} is zero (Etter et al., 2021).

$$E_{AS,P} = E_{p,y} + E_{ap,y}$$

Where (Etter et al., 2021):

$E_{AS,P}$ - Project emissions in year x from application (tCO_2e)

$E_{p,y}$ - Emissions from the production of biochar in year x (tCO_2e)

$E_{ap,y}$ - Emissions from applying biochar in year x (tCO_2e)

3. FEASIBILITY STUDY

3.1. Introduction to Study

This section focuses on a feasibility study of biochar production at the Amazon facility in Fargo, North Dakota. It is based on an estimated 5 hectares of land utilized for a stormwater detention basin. This study is being conducted to show the feasibility as well as the applicability of using carbon negative biochar production. The information from the feasibility study can be transferred to other detention basins and green space in the Fargo, North Dakota area or any other areas across the United States utilizing native vegetation to the region. The importance of the feasibility study is set as an example guide of how to properly grown and harvested biomass in a carbon neutral system and produce biochar in a carbon negative system.

The feasibility study consists of a proposal for the work, plant species adapted to survive in periodic wet periods of a detention basin in the Fargo area, importance of wet/mesic seed mixes, costs associated with the project, and benefits both direct and indirect. These sections will demonstrate the feasibility of biochar production, costs, and how to implement at not only the Amazon site, but other basins and green spaces in Fargo as well. It is worth noting that the importance of basin restorations and biochar production is not limited to Fargo, North Dakota. Potential sites, no matter where, can utilize its own unique set of vegetative species to meet a similar set of goals and objectives.

3.2. Proposal

The Amazon Fargo Facility in my Feasibility Study is based on a 5-hectare detention basin space in Fargo, North Dakota (Figure 3.1). Each aspect of this study can be changed to scale to meet the needs and demands of other projects. Additionally, there are variables that come with the project to meet specific goals and objectives. However, projects should be designed to ensure no carbon emissions are being produced in the process. This includes having a kiln on site where biomass is not being transported to a different location using carbon emitting transportation fuels. The specified resolutions set by an individual company will determine the size, extensiveness, and feasibility of biochar production on a given site.

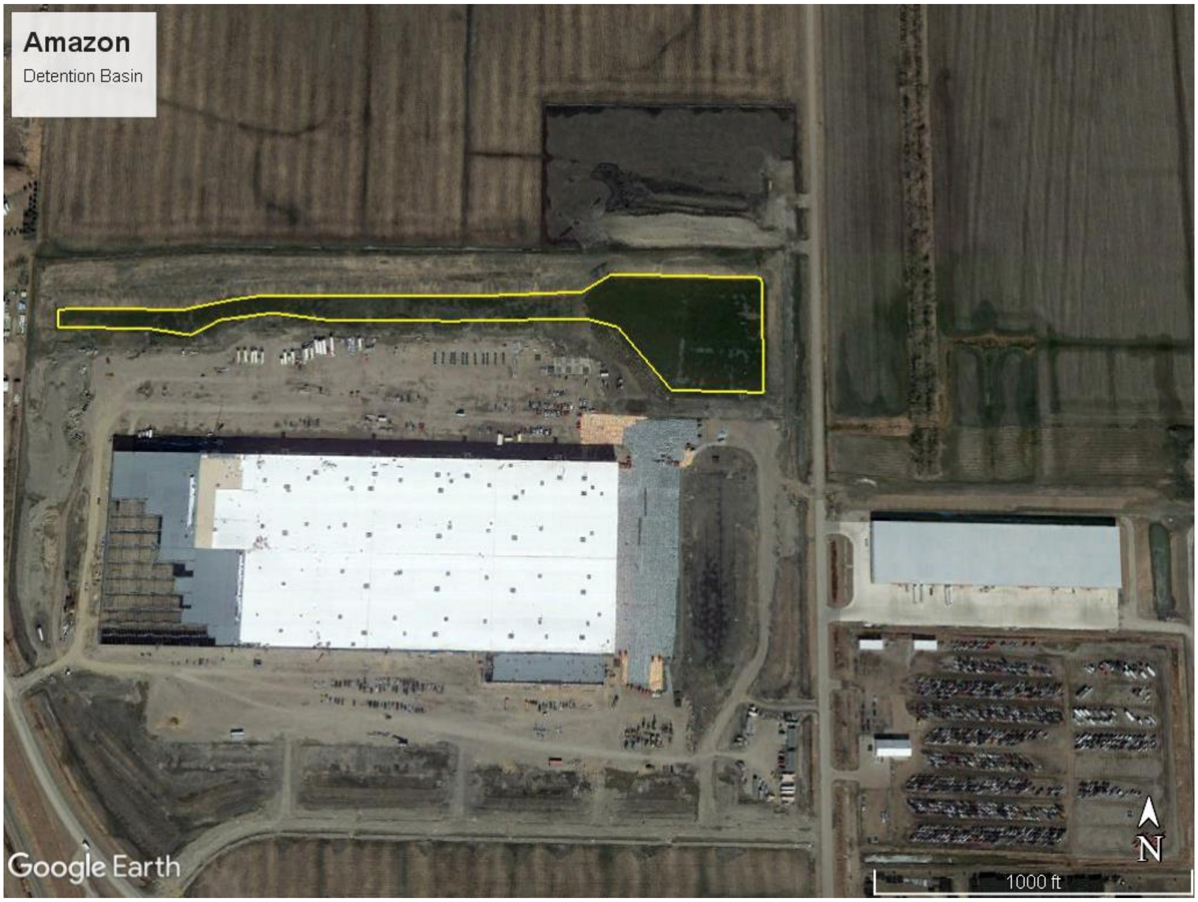

Figure 3.1: Amazon Fargo Facility Detention Pond in Yellow
Source: Google Earth and City of Fargo, 2021

The first two years are being spent establishing herbaceous vegetation on the location for biomass production. In Figure 3.1, the area marked in yellow is our primary focus for herbaceous biomass production. Given there are many unknowns, there could potentially be a burn for site preparation, seeding, reseeding occurrences for proper vegetation establishment, mowing for first two years, and use of adaptive management on site. Of course, many aspects depend on landscapers hired, and exact goals and objectives set in place for each site.

After vegetation has been established, biochar harvesting can begin. Harvesting will only happen once a year in late fall after plant senescence has occurred and the vegetation has reached below 25% moisture content (Sadaka et al., 2014). Harvesting will be done by utilizing a battery-operated all-terrain vehicle (ATV), which allows for no emissions released during the harvest of biochar. The ATV will be used to cut the vegetation using a ground driven sickle mower. The cut vegetation will be baled using a ground driven baler with bale size matched to biochar kiln size. To ensure there is no emissions released during the production of biochar, there is a need to charge the battery-operated ATV with solar energy (or another renewable source). If there is a utility shed for storage of the ATV as well as bales/biochar, it could have a solar panel installed for that very purpose.

There are kilns available for purchase for biochar production, however, ones that release the least emissions are not readily available in the United States. The technology and plans available for building biochar kilns are available[1]. More research is needed to find the best kilns available for purchase and/or build one on site which is made specifically for the project to allow a catered machine to run at the highest efficiency for any proposed project. Currently most biochar is produced from wood waste and burned in a pyrolysis machine. These are typically found at landfills and use natural gas to heat woody biomass, which means most of these systems emit CO_2.

Kilns are limited in the amount of biomass they can convert given their relative size; however, they can be adapted to specific needs of a site and can be started by using carbon neutral biomass feedstocks such as a few logs or harvested biomass for fuel (Lehmann & Joseph, 2015). Once ignited, biochar kilns can utilize the within kiln evolution of bio-oil for a fuel source

[1] https://biochar-international.org/stoves/

to complete the process. Additionally, though not on the market as of this writing, there is potential for solar powered kilns for biochar production. Kilns are small enough to be on site for biochar production which limits transportation costs and carbon expense. Given the reasons stated, it is recommended to build a kiln on site specified to the needs of the project's goals and objectives.

Large pyrolysis systems offer limitations for carbon neutral biochar production. These systems can convert large amounts of biomass to biochar, but it is produced using propane or natural gas which emits carbon (Khodaei et al., 2020). A goal for biochar production in this feasibility study is to do so in a carbon neutral manner. Large pyrolysis machines which use propane reduce the carbon sequestration potential of the project. Additionally, it is proposed that having an onsite system allows for a reduced carbon footprint since there is not a need to haul biomass in to be converted to biochar.

Using a bale size of 27 kg and 0.3556 meters wide by 0.4572 meters long (Shewmaker & Thaemert, 2004), as an example, after harvest in late fall, it is estimated that there will be near 245 bales (on average) for biochar production (48.92 bales per hectare). Biomass per hectare is 3.59 metric tons and per five hectares is 17.95 metric tons (Casler et al., 2017). Using other biochar kiln specifications, I estimate each bale will take around 8 hours of burn time to turn biomass into biochar. If we estimate the biochar device will run 4 days a week (this is excluding weekends as well as holidays) then one can burn around 208 bales per year in a single bale kiln. Other options are to build a kiln which can burn two bales per day or have two kilns running to increase throughput. Additional options could be to add in biomass from the city of Fargo from wood chips, and a multitude of other scenarios which could be explored. Although anything that requires transportation of biomass will need to require an electric vehicle to remain carbon neutral. Options to expand are available however, it would need to be further explored.

Biochar is not the only product produced in the pyrolysis process. At higher temperatures, bio-oil is produced at a higher yield than biochar and a maximum yield of bio-oil is produced at 500 degrees Celsius (Yoder et al., 2011). The ratio of biochar and bio-oil are directly correlated to type of feedstock and temperature. To obtain high quality biochar and less bio-oil there is a need to find a balanced ratio by utilizing a lower pyrolysis temperature and a slower heating rate. Low and slow temperatures and heating time helps produce more biochar and less bio-oil (Yoder et al., 2011).

Moisture in biomass plays a role in the effectiveness of biochar production (Nsamba et al., 2015). Moisture impacts the performance of pyrolysis systems and can impact the conversion efficiency of biomass to biochar. Additionally, moisture can lead to a loss of heat which impacts the effectiveness of the process. Moisture over 67% is inefficient for production. Overall, moisture reduces thermal energy and forms additional CO_2 because of a shift in reaction from water lowering temperatures. The process leads to a low calorific value gas and while more CO_2 is consumed, additionally, more CO_2 is formed (Nsamba et al., 2015). Harvesting in late fall when vegetation is at its driest will help offset the implications of high moisture content in biomass. Moisture content of switchgrass during late fall is around 17.9% (Ashworth et al., 2017).

The maximum percent of biochar that can produced is around 30-35% of the original biomass depending on the kiln operating temperature and time (Mahinpey et al., 2009). Biochar produced from grasses and forbs will contain similar structure so most of the particles will be between 3 mm and 40 mm in width with varying lengths. Given the size of the particles can be small and may become smaller with handling, such small particles can be subject to carbon loss, which is another reason to utilize it in restoration sites where sites are less disturbed. Less disturbance from actions such as tillage will help with the long-term stability of biochar.

Once biochar is produced, it will be up to Amazon or other entity to decide how to best utilize it for carbon sequestration. At this point, we suggest Amazon donates to organizations for ecological restorations to receive the maximum benefit from the carbon sequestration with an emphasis on wetland and anerobic sites. Biochar is a product that can be sold, however, using it in agricultural practices (it's primary consumer) does not have the exact same benefit as a restoration project where the land after is not tilled. Tilling land with agricultural practices can release carbon from buried biochar. There is uncertainty to how much loss there will be of biochar in agriculture systems. However, when utilized in restorative projects such as prairie restorations and/or wetland restorations, it can stay in the ground for a millennia and enhances the carbon sequestration rate which offsets impacts of climate change (Monroe 2016; Schmidt et al., 2018).

3.3. Comparison of Forested Systems

There are different carbon sequestration systems being utilized with varying technology, cost, and effectiveness. As we learn more about our changing environment, it is important to adapt plans which are viable to changing climates. Forested systems have been highly sought after for carbon reduction potentials. It is important to look at comparisons between systems to ensure sustainable carbon storage.

Reforestation plays a vital role of importance in ecosystems that have been displaced for logging or competing land uses. However, these projects are not cheap. Some studies estimated that costs of reforestation in Oregon after a 2002 fire were anywhere from $617.5-$4,940 per hectare (Gorte, 2009). This leads to an average of $1,291.81 per hectare of cost. Additionally, at the high end for an estimated reforestation of 182 million hectares, at $4,940 per hectare, the cost would be around $900 billion (Gorte, 2009).

On average, trees can sequester anywhere from 2.72 – 19.03 metric tons of CO_2 per hectares per year according to the EPA (Gorte, 2009). This number can be highly variable depending on tree species, success of plantings, and age of plantings. One of the large downfalls of carbon sequestration from forested systems is on average it takes twenty years for many species to reach peak age for carbon sequestration potential. When observing the Pacific Coast with areas dominated by Douglas fir, it could be closer to sixty years to see peak potential (Gorte 2009).

Trees (as well as other vegetation) capture atmospheric carbon through photosynthesis (Schahczenski & Hill, 2009). Trees store most of the carbon above ground in their stems, branches, and foliage. Branches and leaves which have fallen can add carbon back to the soil and additionally, carbon can be lost back to the atmosphere through respiration and decomposition of organic matter from forested systems (Schahczenski & Hill, 2009).

Table 3.1 below is used to show the impact of carbon sequestration in metric tons per hectare per year and a twenty-year comparison. It is important to see a short term (annual) impact of each system is as well as a long term (20 years) impact. Additionally, grasslands and biochar are separated in the table below but can be combined to maximize benefits. Trees can also be harvested for biochar production, however, growing periods for grasses and forested systems vary greatly.

Table 3.1: Comparison of Three Different Carbon Sequestration Systems in Metric Tons per Year per Hectare (Two Years After Plantings) and a Twenty-Year Average.

System	Carbon sequestered 2 years after planting in metric tons	Hectare	Carbon sequestered 20 years average in metric tons
Forest[a]	2.72 -19.03	1	54.4-380.6
Grassland[b]	4.45-11.61	1	89-232.2
Biochar[c]	17.3	1	346

[a.] Congressional Research Service, 2009
[b.] Michigan State University, 2011
[c.] University of Massachusetts Boston, 2017

Though Table 3.1 above shows an average of carbon sequestered in these systems given the high amount each system can sequester as well as the low, it is highly unlikely that forested systems will sequester as much per metric tons annually until it is closer to the 20-year growth mark. Whereas grassland systems with biochar production can sequester up to 27.18 metric tons per hectare annually after year two of planting. It is important to look at both systems which are helpful now as well as future systems that can sequester carbon. Climate change is accelerating each day and we need to implement action that is reducing carbon as soon as possible (IPCC, 2021). Given the rising rates in temperature, there is a need to implement action that will have immediate benefits to offset CO_2 emissions. Below, Table 1.3 shows the difference for a forested system as well as a biochar production with grasslands sequestration for a twenty-year comparison.

Table 3.2: Twenty Year Comparison of Carbon Sequestration in Forested System and Biochar Production in Grasslands.

Total carbon sequestration for forested system	54.4-380.6 metric tons/hectare
Total for biochar production with grasslands sequestration	435- 578.2 metric tons/hectare
Difference between biochar grassland and forested system	197.6-380.6 metric tons/hectare

Numbers taken from Table 1.2

With the spread of climate change as mentioned earlier, wildfires have become fiercer and more frequent (IPCC, 2014). Trees sequester carbon in their above ground structure and grassland systems sequester much of that into their root systems and into the soil carbon system

(Gorte, 2009). Compared to forests grasslands emit less carbon when burned and retain more carbon for sequestration. Wildfires can not only release carbon in forested systems, but it derails all progress needed for mature trees to sequester carbon (Gorte, 2009). In contrast, grasslands often grow as much biomass prior to the wildlife in the years immediately following wildfires and carbon is more stable below ground when such a disturbance occurs.

Climate change comes with increases of disturbances which includes more frequent and severe droughts (Bennett et al., 2015). Droughts impact the stability and health of forests and can impact even large trees that are keystone species in forests. Thus, droughts can impact carbon storage in forested systems. Climate change has a direct link to water deficits and more severe and frequent droughts are expected as changes in precipitation and temperature continue to change. Large trees are impacted as well as small trees, however, seedlings may not survive if planted in drought conditions. Mortality rates of large trees is impacted greatly in drought years (Bennet et al., 2015). If seedlings cannot be established during droughts, and large trees are stressed from disturbance, we may not be able to rely on the carbon storage potential of forested systems as our climate continues to change. Grasslands on the other hand are more resilient to increasing temperatures, drought, fire, and can sequester carbon belowground (Dass et al., 2018). These defining features make grasslands a more suitable option for carbon sequestration, especially in areas which are observing high impacts of climate change.

3.4. Importance of Wet/Mesic Seed Mix

Detention basins will need two primary landscaping mixes, one wet meadow mix, and a mesic mix. The exact seed mixture curated, will depend heavily on on-site conditions, soil health, and the composition of topsoil. The wet meadow mix will be for deeper areas of the basin subject to longer flooding and wet soils, whereas the mesic mix will be closer to the top of the basin where flooding is less, and soils will dry out periodically. When looking at both mixes, there is a need to heavily weigh benefits of providing habitat for pollinators. Proposed seed mixes for Fargo, North Dakota detention basins can be seen in Appendix 1.

Plants that withstand wet conditions such as, Liberty Variety Switchgrass *(Panicum virgatum L.)* (Vogel et al., 2014), Red River Natural Germplasm Prairie Cordgrass (*Spartina pectinate)* (Boe et al., 2009), and 'Mandan' Canada wild rye *(Elymus canadensis)* (Vogel et al., 2006) are viable options for biochar production (Vogel et al. 2014). In mesic conditions, farther out of the basin, Big Bluestem *(Andropogon gerdardii*), Indian Grass *(Sorghastrum nutans)*, as well as pollinating forbs, can be considered and selected based on seed mixes available for purchase, as well as examining plantings which are beneficial to species such as monarch butterflies *(Danaus plexippus)*.

Seed mixes can be modified and determined based on-site conditions, target species, and seed availability. In addition, higher biomass yields should be considered to maximize benefits when contemplating seed mixes. Mowing may be necessary in first one-two years following planting on site location to eliminate any competitive weeds (Kurtz, 2013). Once seedbeds have been established, harvesting will happen in late fall to ensure maximum benefits are reached on site, such as habitat for pollinators, carbons sequestration from planted materials, and ecological services provided from plants in a detention basin. Additionally, fall is when vegetation is at its driest which is essential for producing biochar.

Pollinators will be the primary target species considered in this feasibility study which can utilize the Amazon site. Pollinators can include the entire landscaping of a facility and is not limited to basins which will be harvested for biochar production. To promote their presence, adding beehives in the area will also promote local industry. Promoting pollinators has recognized benefits, but hard to monetize for the sake of a cost/benefit analysis.

The second target group for this feasibility study was avian species. Planting habitat for migrating birds is beneficial. In addition, putting up bird houses for species such as Tree Swallows *(Tachycineta bicolor*) and Wood Ducks *(Aix sponsa)* (Ardia, 2013). Again, vegetation put on site will depend on what is possible for habitat for specific species, each area of focus will have different target species. It is worth noting to avoid promoting habitat for ground nesting avian species as detention basins will periodically be flooded.

Allowing a mixture of landscaping to occur instead of mowed green space greatly promotes the biodiversity and ecological benefits associated with quality habitat (Yang et al., 2019). Additionally, tall grasses promote better water infiltration as an ecological service (Dreher, 1999). Mowed areas with short growing vegetation and less extensive root systems create areas of more runoff compared to tall grasses. Runoff is where soil and nutrients are carried off a site. When promoting tall grasses with extensive root systems, there is higher infiltration, less soil erosion, and less pollution of surface waters (Dreher, 1999).

3.5. Costs

One-time capital costs associated to start the process of biomass harvest and collection for biochar production is estimated to range from $35,975-$58,675 (Table 2.1). This includes electric run ATV, bailer, and biochar production equipment needed for the 5-hectare site. The harvesting equipment and process along the facility is designed to be carbon neutral. The feasibility study assumes only renewable energy is used to run the equipment to allow for a sustainable operation. This will reduce the carbon footprint of the production of biochar. The feasibility study envisioned that a landscaper already part of the Amazon campus or Amazon employee will oversee operating and running the biochar kiln as well as harvesting of material annually in the fall. Using personnel already on staff will reduce the costs of producing biochar. Potentially this system could be implemented at facilities with detention basins in the same region. Biochar is a unique option for carbon sequestration given it is a system that is carbon negative. It is a necessary and important component to mitigate climate change.

Table 3.3: Estimated Budget for Biochar – Fargo Amazon Facility Based on a 5-Hectare Detention Basin.

Materials Needed	**Measurements/Materials**	**$ Per Unit**	**# Of Units Needed**	**Comments**	**Total**
Battery Operated ATV[a]	Harvesting of biomass for biochar production		1 per site		$11,000
Power Take Off Cart and Sickle Bar[b]	Harvesting of biomass for biochar production		1 per site		$9,775
Baler[c]	Harvesting of biomass for biochar production		1 per site		$9,000 - $19,000
Biochar Kiln[d]	Kiln for heating biochar		1 per site	Preferably a kiln that is made specialized for each size and location to meet the exact needs and demands	$5,000-$15,000
Shed to store landscaping equipment/biomass[e]			1 per site		$1,000-$3,000
Solar Panels to power shed to charge ATV[f]			1 per site		$200-$900
Capital Costs					$35,975-$58,675

Quote Estimates Provided By:
[a.] Eco Charger E-ATV https://ecochargerquads.com/lithium-power
[b.] Skid Steer Solutions https://www.skidsteersolutions.com/skid-steer-sickle-bar-mower-attachment-eterra/
[c.] Tractor Tools Direct https://tractortoolsdirect.com/
[d.] Alibaba.com
[e.] Home Depot homedepot.com
[f.] Home Depot homedepot.com

3.6. Benefits

Current projections for native grasslands planted alone, without the utilization of biochar, sequester upwards of 4.2 metric tons per hectare per year of carbon (Garcia-Alverez, 2011). The exact amount of carbon sequestration from biochar application is dependent on the plant material selected as well as the restoration site it is applied to. Applying to restoration projects for native grasslands have a higher atmospheric sink rate than those of agricultural lands where soil disturbance happens more frequently (Popkin, 2021). Exact calculations will need to wait for further assessment of the site and details of the project. Each site will need to establish vegetation suited to the area and provide habitat for species protection within the set guidelines of goals and objectives of which they strive to accomplish.

Planting native grasslands promotes biodiversity in urban areas which has largely impacted habitat and strain on species from habitat fragmentation (Filazzola et al., 2019). Given the size of the site for the Amazon facility in Fargo, North Dakota, there is a need to make restoration and sustainability part of their campus. Biochar will only be harvested in late fall after all benefits of the habitat have been maximized. In addition, this is when the lowest water content should be in plant material. It allows space for pollinators and other species to thrive from the 5 hectares of restoration.

Given the site is near the airport, there is a need to ensure Canada goose (*Branta canadensis)* and other large avian species are not drawn to the location. Mowing the site consistently will promote habitat for Canada goose as they are attracted to other basins in the Fargo area for similar reasons. Allowing tall grasses to thrive on the landscape, lowers possibility of large avian species which will prefer other mowed green spaces. This allows Amazon to comply with desires of the airport which is concerned about safety. Each project will have a unique set of species and stakeholders in proximity they will need to account for. Any changes in plant composition can provide benefits as well as challenges which will need to be observed and attended to.

Allowing tall grass prairies to be on site, provides an economic benefit due to less maintenance. Mowing can become a substantial amount given the size of the site. On average, the city of Fargo estimates around $1,482.63 per hectare for mowing each year. With 5 hectares, it will average around $7,413.16 for the stormwater basin landscaping annually (Table 3.4). In around six years, the project initial funding will have paid for itself alone from the offset maintenance costs associated with consistent mowing.

Aside from benefits associated with no mowing, there are other indirect benefits associated with native plantings on a detention basin. Biochar holds a value seen below in Table 2.2, typically the value has been held as a soil amendment. If the company chooses, they could sell biochar as a product for soil amendments, carbon filters, etc. Carbon sequestration from vegetation holds a value through carbon credits. Though some of these are still new and developing, below you will see an estimate based on carbon credits value and the metric tons of carbon sequestered per hectare of grasslands, as well as additional carbon sequestration value from biochar production as well.

Other indirect benefits associated with restorations which include ecological services. Ecological services are those that address air quality, competing needs between humans and wildlife, soil fertility, nutrient cycling, pollination, water purification and infiltration, genetic diversity, climate regulations, etc. (Feng et al., 2014). Some are hard to put a value on as they do not hold the same standard monetary value as something more tangible. Table 2.3 below shows a rough estimate of the valuation of these ecological services. However, some of which such as pollinator habitat for bats, bees, flies, moths, birds, and butterflies that provide pollination service is estimated at around four to seven billion dollars and aesthetics value alone is $280 million a year in the United States alone (Krieger, 2001).

Total value of benefits both direct and indirect equate to around $26,935- $31,502 annually for 5 hectares of land. Over a five-year period that value is $134,677-$157,512 in value from both direct and indirect benefits all associated with implementing a carbon negative system. These values are subject to change and would need to be assessed annually on site to ensure maximum benefits are being reached. Additionally, some of these items, such as biochar hold cumulative values. Again, this is something that needs to be assessed annually. Values are seen in metric tons of carbon sequestered. Table 2.4 shows values in CO_2e.

Biochar production varies based on amount of biomass produced annually. On average, 30% of biomass is converted into biochar using slow pyrolysis methods. Switchgrass production equates to around 3.59 metric tons per hectare annually (Casler et al., 2017). The estimated production of this can be seen in Table 2.2 below.

Table 3.4: Biomass to Biochar Conversion Metric Tons Per Hectare

Biomass production per hectare[a]	Conversion to biochar[b]	Total hectares	Annually	5- years
3.59 metric tons	1.077 *(3.59 *30%=1.077)*	5	5.385 *(1.077 * 5=5.385)*	26.925 *(5.385*5=26.925)*

a. South Dakota State, 2017
b. Bioresource Technology, 2013

Table 3.5: Estimated Benefits Direct and Indirect

Materials	Measurement	# Of Units	Comments	Total Annually	Total 5-years	Benefit
Mowing[a]	$1,483 per Hectare	5 Hectares	Mowing will only need to continue for the first year-two years following restoration planting. After, it is only for harvest.	$7,415	$37,075	Direct
Biochar value[b]	$2,580 per metric ton	3.59 metric tons biomass per hectare[c] 30% biomass to biochar[d] 1.077 metric tons per hectare 5.385 total for site	Yields may vary and can be adjusted on an annual basis	$13,893	$69,467	Direct
Carbon Sequestration (From vegetation alone) Estimate[e]	$30- $90 per metric ton/hectare	3.46 – 9.88 metric tons per hectare	5 hectares	$519 - $4,446	$2,595- $22,230	Direct
Carbon Sequestration (From Biochar)[f]	$82-$119 per metric ton/hectare	17.29 metric tons	5 hectares	$1,418- $2,058	$7,090- $10,290	Direct
Ecological Benefits (Estimate)[g]	$738 per hectare (median value)	5 hectares	Median value based on average collected from multiple sources	$3,690	$18,450	Indirect
Total			Does not include all benefits	$26,935- $31,502	$134,677 - $157,512	

Quotes Provided By:

[a.] City of Fargo

[b.] Farm Energy Extension. https://farm-energy.extension.org/biochar-prospects-of-commercialization/#:~:text=The%20average%20price%20for%20biochar,of%20its%20unique%20chemical%20properties.

[c.] South Dakota State. https://openprairie.sdstate.edu/cgi/viewcontent.cgi?article=1121&context=plant_faculty_pubs

[d.] Bioresource Technology. https://www.sciencedirect.com/science/article/abs/pii/S0960852413013862

[e.] Center for Climate and Energy Solutions. https://www.c2es.org/document/the-cost-of-u-s-forest-based-carbon-sequestration/#:~:text=Estimated%20costs%20for%20sequestering%20up,%2430%20to%20%2490%20per%20ton. University of Massachusetts Boston. https://ag.umass.edu/sites/ag.umass.edu/files/reports/timmons_-_biochar_report_10-16-17.pdf

[f.] Ranchers Stewardship Alliance Inc.

[g.] https://www.pcap-sk.org/rsu_docs/documents/Native_Grassland_EGS_RSA-sm.pdf

Table 3.6: Amount of CO_2e[a] in Metric Tons Per Hectare

Item	**Metric Tons of CO_2e**	**Hectares**	**Total Metric Tons of CO_2e**
Biochar Fixed Carbon[a]	2.57 *(1.077*0.65*3.67)*	5	12.85
Vegetation (CO_2e) Sequestration Amounts	12.7 – 36.26 *(3.46 – 9.88*3.67=12.7-36.26)*	5	63.5 – 181.3
Biochar (CO_2e) Sequestration Amounts	63.45 *(17.29*3.67=63.45)*	5	317.25

Annual CO_2e sequestration potential – Values converted from Table 2.3

Atomic weight of carbon is 12 atomic mass units, carbon dioxide is 44 because of 2 oxygen atoms with a weight of 16. One ton of carbon equals 44/12 = 11/3 = 3.67 tons of carbon dioxide

[a.] Verified Carbon Standard: Methodology for Biochar Utilization in Soil and Non-Soil Applications, 2021

The City of Fargo has an estimated 404.69 hectares of land that is "underutilized" that provide little to no benefit, but are costly to maintain (Monroe, 2016). There is 3.59 metric tons of biomass produced from switchgrass on a hectare (Casler et al., 2017). If the locations were converted for use of biochar utilization and moved to multiuse sites, all unutilized land could produce an estimated 1,452.84 (3.59 metric tons of biomass * 404.69 hectares = 1,452.84) metric tons of biomass. Observing information provided above in Table 2.4, the CO_2e of each hectare is anywhere from 76.15 – 99.71 metric tons annually. Fargo having 404.69 hectares of underutilized land could sequester anywhere from 30,820.95 to 40,351.64 metric tons of CO_2e annually. Other cities potentially have similar areas that could be used to produce biochar and sequester carbon.

4. CONCLUDING POINTS

Biochar is a feasible and plausible option for climate change solutions which should be considered as a top priority for implementation. Other measures such as forested systems, are limited by our changing climate. Extreme drought events as well as wildfires degrades carbon sequestering abilities in trees. It is clear the best and most concise way to produce biochar is to localize the entire process to ensure no extra carbon emissions are being emitted in the process. This includes growing, harvesting, and burning biochar on site. This allows for little to no transportation and will help increase the benefits associated with a carbon negative system.

There is a need to further research into the most efficient kilns with little to no emissions. There are many companies who have similar technology, but it is not being utilized to produce biochar currently. Funding will need to be provided to create a prototype that best suits the needs of an emissions free kiln. There also needs to be more research into carbon credits associated with biochar and the differences between soil carbon capture as well as anerobic wetland carbon capture to maximize benefits of biochar.

Additionally, there are many variables with biochar such as what to do with the product after it has been produced. These variables can change depending on exact goals and objectives of a particular company or organization. Biochar can additionally be produced from many different biomass materials and is by no means limited to grassland ecosystems. This overview was here to showcase the importance of biochar in our fight against climate change and give a feasible case study to show how it can be implemented.

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APPENDIX PROPOSED PLANT SPECIES FOR FARGO, NORTH DAKOTA BASINS

Design Seed Mix (Basin)	**60% Grass/40% Forbs**
Liberty Switch Grass	*Panicum virgatum*
Mandan Canada Rye	*Elymus canadensis*
Yarrow	*Achillea millefolium*
Black-eyed Susan	*Rudbeckia hirta*
Golden Alexander	*Zizia aurea*
Blue Vervain	*Verbena hastata*
Panicle Aster	*Symphytrichum lanceolatum*
New England Aster	*Symphyotrichum novae-angliae*
Common Ox-eye Sunflower	*Heliopis helianthoides*
Wild Bergamot	*Monarda fistulosa*

Bottom of Basin (only planted at low points)	**Established to wet conditions**
Prairie Cord Grass	*Spartina pectinate*
Swamp Milkweed	*Asclepias incarnata*

Erosion Mix (only planted where there are concerns of erosions)	**Still seeded with basin mix as well**
Annual Rye or Oats	(Open to what is available)

Spike Mix (Flowers that bloom quick)	**Upland area seeding for more forbs**
Black-eyed Susan	*Rudbeckia hirta*
Yarrow	*Achillea millefolium*
Purple Prairie Clover	*Dalea purpurea*
Wild Bergamot	*Monarda fistulosa*

Upland Seed Mix – Top of Basin	**Adapted to conditions on the top/outside of basin**
Big Bluestem	*Andropogon gerardii*
Canada Wild Rye	*Elymus canadensis*
Slender Wheat Grass	*Elymus trachycaulus*
Liberty Switch Grass	*Panicum virgatum*
Indian Grass	*Sorghastrum nutans*
Anise Hyssop	*Agastache foeniculum*
Common Milkweed	*Asclepias syriaca*
Butterfly Weed	*Asclepias syriaca*
White Prairie Clover	*Dalea candida*
Canada Tick Trefoil	*Desmodium canadense*
Golden Alexander	*Zizia aurea*
Blue Vervain	*Verbena hastata*
Culvers Root	*Veronicastrum virginicum*
Mountain Mint	*Pycnanthemum*
Long-Headed Cone Flower	*Ratibida columnifera*
Smooth Blue Aster	*Symphyotrichum leave*
New England Aster	*Symphyotrichum novae-angliae*
Maximillian's Sunflower	*Helianthus maximiliani*
Common Ox-eye Sunflower	*Heliopis helianthoides*
Prairie Blazing Star	Liatris pycnostachya
Yellow Cone Flower	*Ratibida pinnata*
Stiff Goldenrod	*Solidago rigda*