# THE CARBON NEGATIVE SYSTEM: AN INNOVATIVE SYSTEM FOR SUSTAINABLE COMMUNITY DEVELOPMENT

A Thesis
Submitted to the Graduate Faculty
of the
North Dakota State University
of Agriculture and Applied Science

By

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In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE

Major Program:
Natural Resource Management

October 2016

Fargo, North Dakota

# North Dakota State University
Graduate School

**Title**

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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

It is understood civilization may be entering the Anthropocene Epoch, characterized by human influences on Earth's geology and environment. A growing body of literature highlights the ecological concerns affiliated with anthropocentric influences on the environment. This study indicates climate change and global $CO_2$ emissions as an area of concern, and proposes the Carbon Negative System as a potential solution of many. The Carbon Negative System is comprised of three steps: land use and prairie vegetation, biochar process, and the system benefits. To illustrate these steps and to test the system's viability, a case-study analysis was applied to the community of Fargo, North Dakota. The system is described and its benefits were indicated. A carbon budget and economic analysis were determined, and the system was applied to a resilience framework to synthesize the findings.

Keywords: community development, biochar, prairie vegetation, ecosystem services, resilience, Anthropocene, climate change, carbon emissions

# ACKNOWLEDGMENTS

## Personal Growth

My graduate education has been a truly formative and fulfilling experience. I would not be confidently entering the workforce if it were not for the advising and guidance of a brilliant group of mentors. At this time I would like to thank Dr. Robert Littlefield and Dr. Jack Norland for fostering my intellectual growth, while tolerating my independent nature.

Additionally, thank you to Dr. Christina Hargiss, Dr. Shawn DeKeyser, Dr. Nan Yu, and Dr. Bruce Steele. It is thanks to you I am able to understand and articulate concepts across a variety of disciplines. Finally, I would like to thank my friends and family for supporting me throughout my graduate experience. Without your support, I would not have been able to find the balance needed to achieve within the rigors of a graduate education.

## Carbon Negative System

The conceptualization of the system occurred through NDSU’s Innovation Challenge 2016, with the help of teammates Jesse Riley and Alexis Steinman, and the advising of Dr. Norland. In addition to thanking the team, I would also like to thank Dr. David Ripplinger, Curtis Borchert, and all who assisted or endorsed our efforts in the competition. Finding solutions for natural resource challenges is equally as multidisciplinary as it is a collaborative effort.

# DEDICATION

This paper is dedicated to my strong and caring mother, Tomelyn Taylor.

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# LIST OF ABBREVIATIONS

GHG .....................................Greenhouse Gasses

UNFCCC …………………...United Nations Framework Convention on Climate Change

CNS.......................................Carbon Negative System

CEC ......................................Cation Exchange Capacity

CRP.......................................Conservation Resource Program

EPA.......................................Environmental Protection Agency

NPV ......................................Net Present Revenue

ROI........................................Return on Investment

# CHAPTER ONE

## The Anthropocene

It has been suggested society no longer exists in the Holocene; an epoch characterized by post-glacial geology, beginning approximately 10,000 years ago (Stromberg, 2013). Instead, it is suggested current day civilization lives within the Anthropocene, "The recent age of man," characterized by the impacts humans have on the earth's geological and ecological state. Crutzen and Stoermer (2002) introduced the idea, pointing to the unique characteristics of the expansion of mankind, "both in numbers and per capita exploitation of Earth's resources," and to a growing body of literature that suggests this transition.

Indeed, the International Commission of Stratigraphy, the governing body that determines geological time scale, has taken note of this transitory phase, and constructed a task force to further understand this temporal period. When considering the Anthropocene, it is clear human civilization has had dramatic and profound impacts on the Earth's environment and natural resources. Climate change is a central focus within this concern, and 97% of scientists agree humans are causing recent climatological events (Cook et al., 2016). This study focuses on anthropogenic $CO_2$, as a leading cause for recent climate change.

Berger and Loutre (1996) indicated that because of an increase in anthropogenic emission of $CO_2$, the Earth's climate may depart significantly from natural behavior over the next 50,000 years. The rising temperature of the Earth's atmosphere is the driver of the climate change concerns. According to the Intergovernmental Panel on Climate Change, global temperatures have warmed roughly 1.33°F over the last century, averaging over all land and ocean surfaces (IPPC, 2007).

A growing collection of scientific literature points to dramatic impacts and implications of this rapid temperature increase. Some of the impacts include increased coastal flooding (Adger et al., 2005; Balk & Anderson, 2007; Kirshen et al., 2008; McGranahan,; Nicholls, 2004;), longer and more damaging wildfire seasons (Flannigan & Wagner, 1991; Fried, Torn & Mills, 2004; Isaak et al., 2010; McKenzie et al., 2004; Pinol et al., 1998 ), disruption of food supplies (Poff, Brinson & Day, 2002; Rosenzweig et al., 2001; Schlenker & Roberts, 2008), aquatic (Meyer et al., 2007; Rahel & Olden, 2008) and terrestrial (Gibbons et al., 2000; Kareiva et al., 1993; Thomas et al., 2004) habitat disruption, and increased frequency of natural disasters (IPPC, 2007). It is clear climate change has a wide range of environmental, economic, social, and political impacts (Choi & Fisher, 2003; Haines et al., 2006; Walther et al., 2002).

The Greenhouse Effect is a major cause of the rising global temperatures, and occurs naturally within the earth's atmosphere. This process involves greenhouse gasses (GHGs), which include a number of compounds: water vapor, ozone, carbon dioxide, methane, and nitrous oxide, and other naturally and synthetically occurring compounds within the Earth's atmosphere. The GHGs absorb heat from solar waves and lock them into the Earth's atmosphere, similar to how greenhouses warm their interiors. However, due to human activity, global carbon emissions have increased exponentially, causing the dramatic rise of global temperatures. According to the United States Environmental Protection Agency (2015) "Since 1970, $CO_2$ emissions have increased by about 90%, with emissions from fossil fuel combustion and industrial processes contributing about 78% of the total greenhouse gas emission increase from 1970 to 2011." Similarly, cities and urban areas produce to up to 70% of the human contributed global carbon emissions, while occupying just 2% of the world's total land (UN, 2011).

With the dramatic impacts and immediacy of climate change, leaders from the international community have made several attempts in developing international agreements with the goal of decreasing carbon emissions. The first global agreement to establish long-term objectives to stabilize greenhouse gasses was the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. It became clear stronger action was needed, so in 1997 the Kyoto Protocol was established, setting legally binding targets to reduce emissions 5.2 percent below 1990 levels by 2012. Next, a number of international conferences for members of the UNFCCC were held from 2000 to present day where the Paris Agreement was negotiated and approved by 196 global representatives (UNFCCC, 2016). On Earth Day of 2016, a record number of countries committed to signing the Paris Agreement, committing themselves to limiting the global temperature rise below 2 degrees Celsius (Perez, 2016)

Despite the ambitious global policy efforts, these initiatives have had little to no success in mitigating climate change (Clark, 2012). Due to the limits of governance of international policy and domestic constraints, little progress had been made in curbing global carbon emissions. It is clear these intentions need a more effective outlet.

Since there is evidence to suggest climate change could have dramatic impacts, more could be understood on how to effectively mitigate these impacts through natural systems. This plan B thesis will develop a thorough understanding of existing knowledge and the ability to apply that existing knowledge to a problem of interest. This study proposes an innovative system to address contemporary challenges in atmospheric carbon accumulation and sustainable community development. Through a case-study approach, this thesis explores the environmental and economic viability of the Carbon Negative System (CNS) as applied to Fargo, North Dakota.

While humans struggle to effectively sequester carbon emissions through public policy, prairie vegetation has successfully done so since the Pilocene Epoch, about 5 million years ago (Dorale et al., 1998). The Kyoto Protocol and other emission reduction frameworks acknowledge this capacity in prairie vegetation, and allow for this carbon update to be utilized to meet carbon reduction goals (Cahill et al., 2009). In addition to effective carbon sequestration, prairie vegetation has the ability to provide additional ecosystem services and benefits that will be further explored in this study.

Similarly, biochar, a carbon rich organic product with numerous applications, has existed for thousands of years (Shackley et al., 2016). By coupling the reintroduction of prairie vegetation into our urban communities with existing biochar technologies, communities have the potential to abate carbon emissions while generating new revenue streams. These two components are the framework for the CNS.

The CNS is comprised of three steps: land use and prairie vegetation, biochar process, and the system benefits. After identifying underutilized lands in the city of Fargo, the system proposes planting prairie vegetation throughout the city to increase the productivity and value of these public lands. Next, the plant material is harvested on a rotational basis and processed with additional organic material at the city landfill, to create the biochar product. Three areas of benefits can be seen through this system: land use, biochar, and economic benefits. This system will be further detailed in the following section and in Chapter Two.

## The Carbon Negative System

The first stage of the CNS is planting prairie vegetation on identified underutilized land. This study focuses on the city of Fargo, North Dakota to provide an effective lens of analysis for the system. Fargo is located in the upper Midwest prairie pothole region, and is the largest city in the state of North Dakota. This region was once covered with mixes of tall and short grass prairie, where only 4% of native prairie grasses lands exist today (Samson & Knopf, 1994).

As highlighted in pink in Figure 1.1, the city of Fargo has over 1000 acres (404.69 hectares) of land that can be considered underutilized, as these sites are expensive to maintain and provide little to no additional benefit. The underutilized lands are detention ponds and basins, may be seasonally flooded, wastewater treatment areas, excess land at the landfill, or have been recently acquired through the flood buyouts along the Red River.

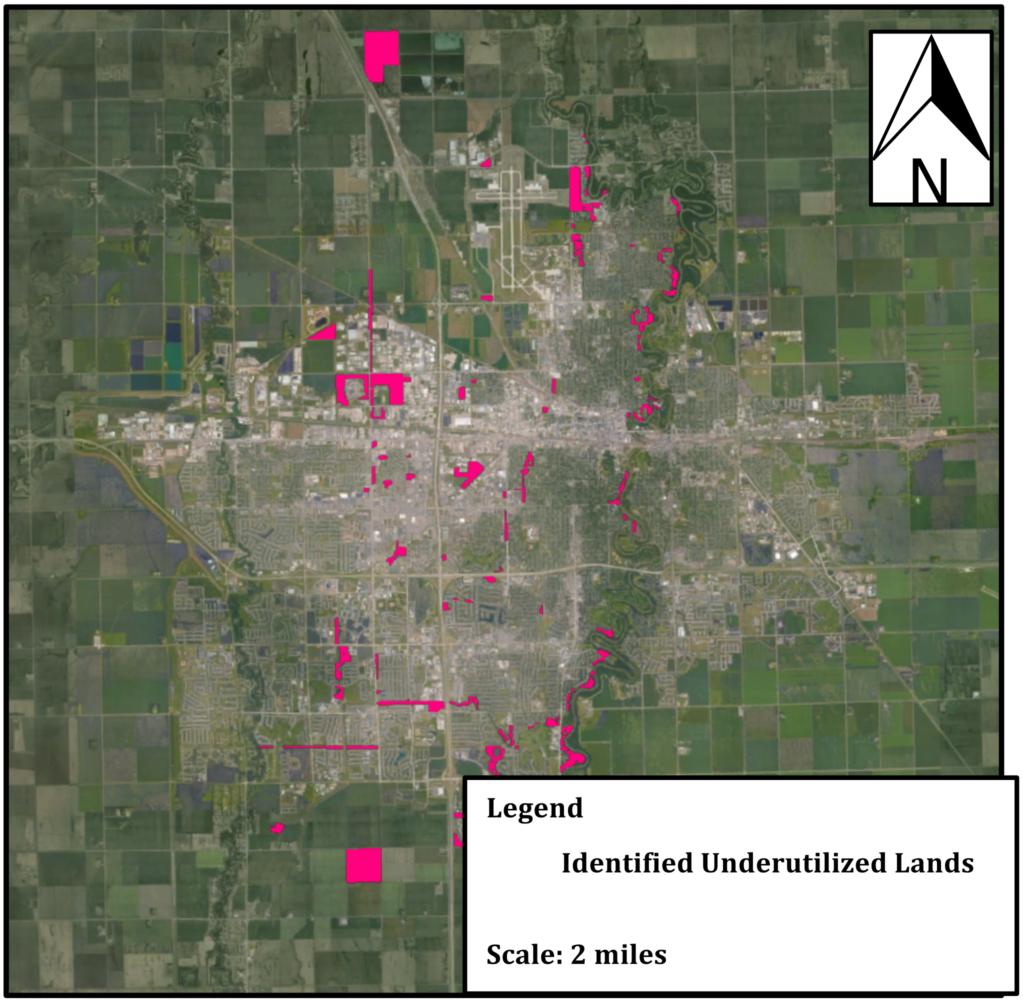

*Figure 1.1*. Over 1000 Acres of Identified Underutilized Land in Fargo, North Dakota. Source: Google Earth & City of Fargo, 2016

The underutilized lands can costs can range from $60,000 to over $100,000 to mow and maintain annually (Dow, 2016). The total cost depends on the amount of precipitation events within the growing season, and will further be explored in the economic analysis section in Chapter Three. Understanding these lands have untapped potential, one option to boost the productivity of these lands may be planting prairie vegetation.

Throughout the growing season, instead of incurring the cost of maintaining these lands, prairie vegetation will effectively sequester carbon emissions while providing additional ecosystem services. These services include, but are not limited to: flood attenuation, increased habitat and biodiversity, water filtration, and increased social values. Prairie vegetation and its ecosystem services will be further explored in Chapter Two.

It is recommended that of these 1,000+ acres some of the vegetation is left untouched to help promote sustainable winter habitat for birds and wildlife (M. Johnson, personal communication, February 9, 2016). While it is important to sustain habitat for these species, an equally important facet of this system is sustainably managing the land. Since controlled burning and other management strategies are difficult to conduct safely in an urban environment, harvesting may be the best alternative in adaptively managing these habitats. After the growing season, some of the prairie vegetation in the system can be harvested and processed into biochar, a charchoal-like organic product.

After the prairie vegetation is harvested within the CNS, it will be transported to the landfill to be processed into biochar. Shackley et al. (2016) defined biochar as:

> Biochar is a solid material obtained from the thermochemical conversion of biomass in oxygen-restricted conditions which is used for any purpose that does not involve its rapid mineralization of $CO_2$. Biochar is commonly used for soil improvement and for the long-term storage of stable carbon (p. 6).

This heating process that creates the biochar product is known as charring or pyrolysis, and is often utilized to make charcoal. Biochar shares similar properties as charcoal, as they are both carbonaceous materials produced by the heating of organic material at high temperature under low oxygen supply (Wiedner & Glaser, 2016). Where biochar and charcoal differ is the range of sustainable benefits that can be achieved.

In the second step of this system, the biochar process, the prairie vegetation and additional organic materials are processed at the landfill in an industrial sized biochar machine.

According to the City of Fargo landfill officials, there are currently 10,000 tons (9,071.85 metric tons) of wood pallets and 10,000 tons (9,071.85 metric tons) of additional organic materials that go unused annually (P. Hanson, personal communication, March 12, 2016). Considering one acre of prairie can produce up to five tons of prairie vegetation (C. Borchert, personal communications, January 12, 2016), approximately 25,000 tons (22,679.62 metric tons) of organic materials can be used within this system in Fargo, North Dakota. While this figure is possible, this study assumes a lower production amount, to account for the variability of natural systems.

The landfill is also home to excess methane produced by waste decomposition processes. City landfill officials indicate the methane produced by the landfill is currently utilized to power municipal facilities, as well as other nearby private facilities. With existing funds to tap into this energy source (P. Hanson, personal communication, March 12, 2016), the CNS could easily utilize the excess methane to power the biochar facility. Within this concept, there is an added benefit from using methane, as it is often considered a worse GHG than carbon emissions. According to the EPA (2015), "Pound for pound, the comparative impact of $CH_4$ [methane] on climate change is more than 25 times great than $CO_2$ over a 100-year period." By preventing methane from entering into the atmosphere, the CNS sustainability produces biochar, thereby offsetting any emissions.

As pictured in Figure 1.2, the biochar process first begins with placing the organic material, or biomass, into the feed hopper. For every 500 pounds (226.80 kg) of plant material fed into the biochar machine, 300 pounds (136.01 kg) of biochar material will be produced (C. Borchert). An auger system incrementally transfers the organic material to the oven, or the heating source. At this time the oven is heated to 1000°F, powered by the excess methane, and effectively baking the organic material into biochar (Lehmann & Johnson, 2015). This process is known as pyrolysis, which allows the organic materials to keep its original structure and composition, while removing any excess moisture from the organic material. Pyrolysis will be discussed in greater detail in Chapter Two.

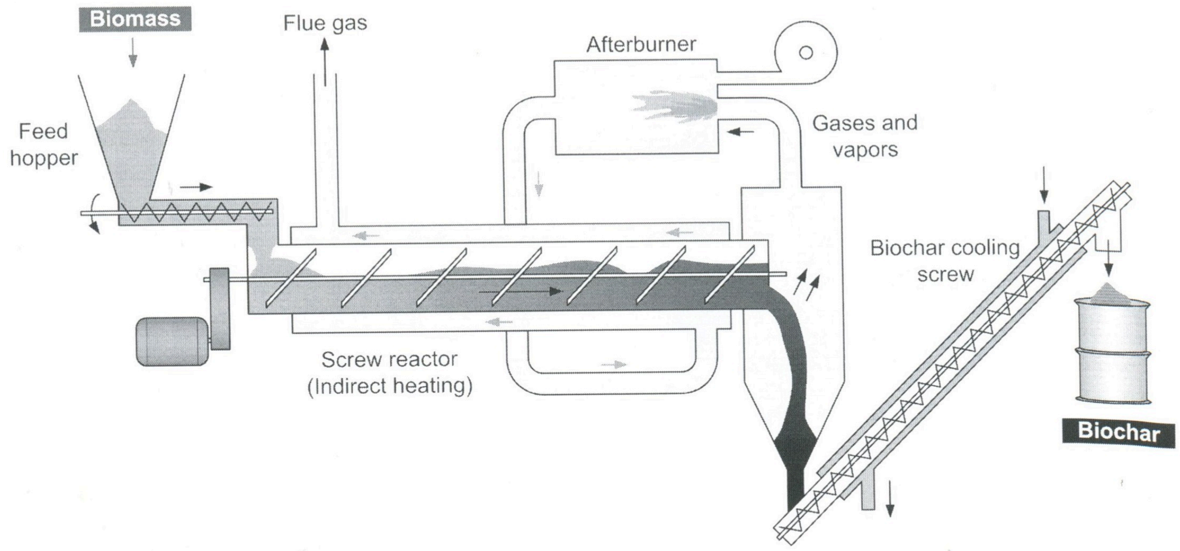

*Figure 1.2.* Biochar Process Model.
Source: Shackley et al., 2016

As the oven removes moisture from the organic material, excess gas and vapors are released. One noteworthy byproduct of the biochar system is the creation of syngas, a synthetic natural gas that may be utilized as a fuel or electricity source. In fact, with this system, syngas has the potential be utilized at the municipal level as a fuel source for internal combustion engines in city vehicles or buses. More benefits will be explored later in this section and Chapter Two.

Finally, after the syngas and biochar are produced, the biochar will be transferred through a second auger system that helps the product cool. The biochar will then exit the biochar process into storage containers where it waits to be applied in countless applications. These benefits will be touched on in this section, and further illustrated in Chapter 2.

The third step of the CNS is the system benefits. After the prairie vegetation is planted on underutilized lands, and later harvested and processed into the biochar product, three primary system benefits can be realized. As depicted in Table 1.1 below, land use, biochar, and economic benefits can be realized with the CNS.

Table 1.1
*System Benefits Overview*

| | |
|---|---|
| *Land Use Benefits* | • Increased Habitat and Biodiversity<br>• Water Filtration & Flood Control<br>• Aesthetic and Social Values |
| *Biochar Benefits* | • Land Application<br>• Water Filtration<br>• Toxin and Pollutant Absorption<br>• Combustion |
| *Economic Benefits* | • Sustainable Economic Development<br>• Political Feasibility<br>• Additional revenues for community development needs |

First, the land use benefits are largely derived from the ecosystem services produced by the prairie vegetation. Currently, the underutilized lands are predominantly covered by Kentucky Bluegrass (*Poa pratensis*), which does little service to providing habitat or biodiversity for these areas (NRCS, 2015). Comparing the status quo to the possibility of dozens of prairie vegetation species, it is easy to visualize the impacts of the increased biodiversity. In Chapter Two, this study focuses on the benefits this system may have for the Western Meadowlark, pollinators, and local bird populations.

Due to the natural processes and properties of prairie vegetation, these lands can become more resilient to dramatic precipitation events (Biggs, Schluter, & Schoon, 2015). Whether it is a flood or drought scenario, water can be effectively retained or controlled with prairie vegetation. Additionally, these plant species are excellent at filtering out toxins and excess chemicals.

Outside of the biological properties of prairie vegetation, a benefit of increased aesthetic and social values can be realized. Aesthetically pleasing natural spaces provide an opportunity to increase the physical and mental health of the community, providing more places to physically enjoy the outdoors. With more accessible natural urban areas, environmental educators can ensure future generations have an opportunity to learn and understand prairie ecosystems. Chapter Two will go into further detail on the listed land use benefits.

Second, the benefits of the biochar product can be realized with the CNS. Whether used municipally, within Fargo’s existing infrastructure and practices, or distributed through the emerging biochar markets, there is a vast array of applications for the biochar product. For example, biochar has been noted to benefit land production, is an efficient absorbent of toxins, and can work as a water filter (Shackley et al., 2016). This study will focus on the land application benefits of biochar.

Finally, the economic benefits can be realized with the CNS. With the growing environmental challenges, communities are often looking to investing in development with an ecological mindset (McGranahan et al., 2005). This focus of sustainable economic development is the cornerstone of the CNS, prioritizing sustainability and resiliency. Additionally, since this system constructs a more effective use of the public lands, and has the potential to generate revenues for the local community, the CNS has tremendous political feasibility. This system has the fiscal and ecological palatability to gain the vital support needed to become a reality. While the benefits of additional revenues for community development vary on the economic scenario, the Fargo community can see an additional $2 to $3 million dollars annually with the CNS. These economic benefits will be investigated further in Chapter Two.

# CHAPTER TWO

The previous chapter discussed the modern challenges of climate change, and a potential solution with the CNS. This chapter will examine four components of the CNS in greater detail: prairie vegetation, the biochar process, carbon budget, and economic analysis. The history, processes, and existing knowledge of prairie vegetation and biochar are presented. Next, the system's carbon budget was calculated along with an economic analysis to determine the system's scientific and economic viability. Finally, each section will conclude with an application to the community of, Fargo, North Dakota.

## Prairie Vegetation

The upper Midwest, once sprawling with prairie vegetation, has experienced dramatic declines in grassland cover. Comparted to pre-settlement coverage, only 4% of North American tallgrass prairie exists today (Samson & Knopf, 1994). Similarly, Noss *et al.* (1995) conducted a study examining the loss of biodiversity at the ecosystem level in the United States. They identified grasslands have declined more than 98%, placing this ecosystem in the critically endangered category. On a global scale, grasslands and prairie ecosystem are considered the most at-risk biomes, largely due to low rates of habitat protection and high rates of conversion (Hoekstra et al., 2005).

An expanding body of knowledge understands the benefits and ecosystem services prairie vegetation and grasslands provide. Prairie vegetation can effectively sequester carbon emissions, provide habitat for wildlife and pollinators, clean and recharge water, while providing flood attenuation. The remainder of this section will focus on these benefits, and how they may be realized in the case-study community.

### ***Carbon Sequestration***

The growing concern for the implications of climate change rests in the rise of increased carbon emissions (Paustian et al., 2016). Pacala and Socolow (2004) have indicated, in addressing this concern, an ‘all of the above’ approach is necessary. This implies solutions need to be feasible, cost-effective, and environmentally sustainable. This study looked to utilize prairie vegetation to effectively sequester carbon emissions, using this criterion.

According to the U.S. Fish and Wildlife Service (2011), “Carbon sequestration is the ability to contain, store or hold carbon through time.” Prairie vegetation naturally collects and sequesters carbon from the atmosphere through the photosynthesis process. The carbon is then used by the plants metabolically, and later stored in the plants tissue. All excess carbon is pumped from the plant to the roots, feeding soil organisms. These organisms help humify the carbon into a stable form, increasing local quantities of soil organic matter (White, Murray & Rohweder, 2000).

Most of prairie vegetation’s ability to sequester carbon happens below ground (FWS, 2011). Figure 2.1 illustrates the root systems of prairie vegetation. An important contrast is drawn between Kentucky bluegrass (*Poa pratensis*), on the far left, and a range of short and tall grasses’ root systems. This juxtaposition indicates the main reason on why prairie vegetation can be considered productive in the CNS. Due to its shorter root system, Kentucky bluegrass has smaller amounts of plant tissue and root systems to store carbon. Prairie vegetation can have up to 15 feet or more of root length (Conservation Research Institute, 2015), indicating with a larger mass and root system composition, prairie vegetation can store more atmospheric carbon. By converting the underutilized land to prairie vegetation, Fargo can increase its ability to sequester carbon emissions through natural processes.

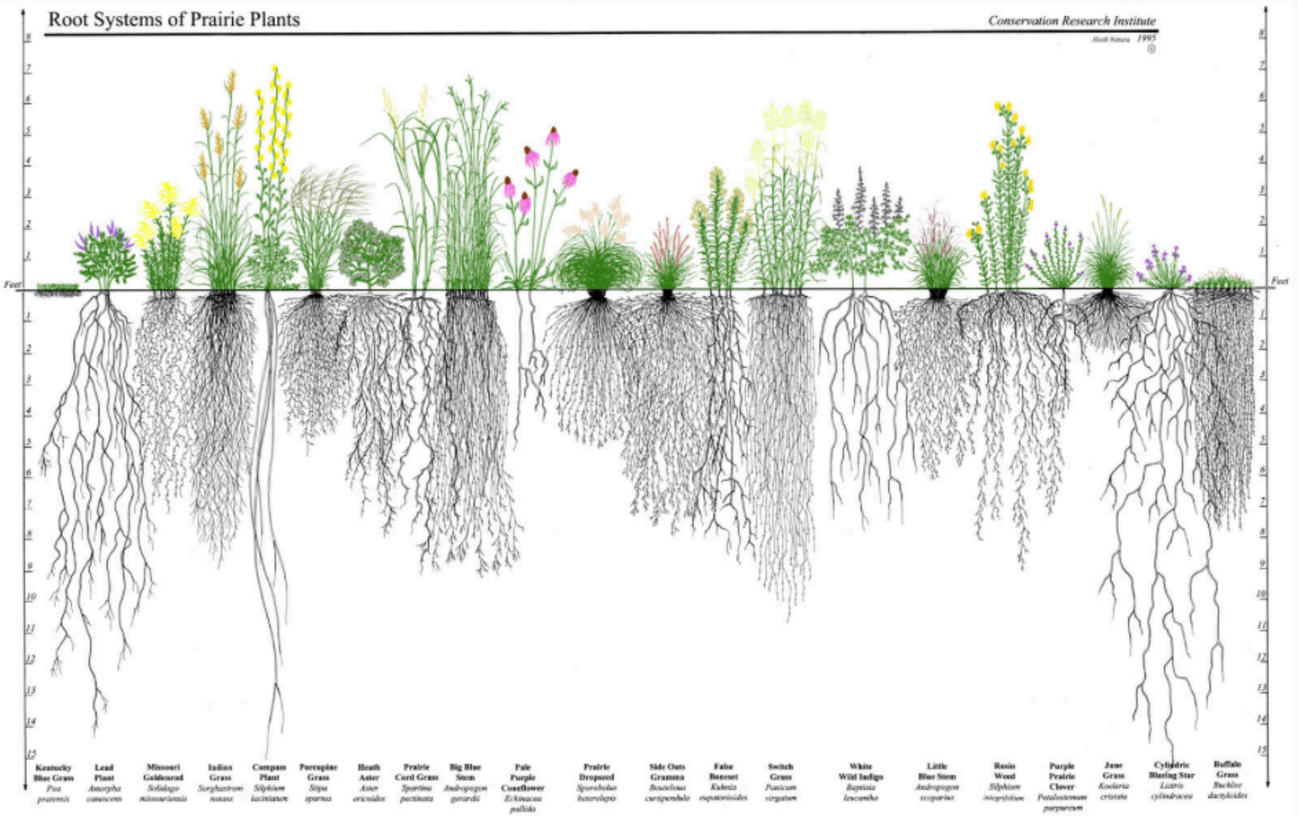

*Figure 2.1.* Root Systems of Prairie Plants.
Source: Conservation Research Institute, 1995

While it is clear prairie vegetation has the capacity to sequester carbon emissions, the rate of carbon sequestration varies amongst studies (Paustian et al., 2016). The carbon sequestration capacity of prairie vegetation has been documented to range from .35 kg/C/ha/year (Conant, Paustain & Elliot, 2001) to 2 x $10^3$ kg/C/ha/year (McCully 2011). This variance is covered in greater detail later in the carbon budget of the study. Ultimately, this study assumed a mean annual carbon accumulation rate of 200 kg/C/ha/year (Cahill et al., 2009).

When analyzing urban vegetation, Dobbs, Nitschke, and Kendal (2015) determined as more cities and urban communities invested in large patches of diverse vegetation, their ability to sequester their carbon emissions increased. To bolster these findings, Dr. Cynthia Cambardel, a soil scientist with the USDA, indicated prairie vegetation can store more carbon underground, than a forest can potentially store above ground (FWS, 2011). The ability to lock and store carbon underground has a profound effect on the fertility and productivity of the soil, which will be further examined in the biochar section of this chapter. Prairie vegetation has a strong capacity to effectively sequester carbon emissions due to its composition and natural processes (FWS, 2011).

### ***Habitat and Biodiversity***

In addition to the ability to sequester carbon emissions, prairie vegetation has the potential to provide more biodiversity and habitat. As defined by the Convention on Biological Diversity:

> "Biological diversity" means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems (Convention on Biological Diversity, Article 2, 1992).

This definition can be understood if broken down into three levels: species diversity, genetic diversity, and ecosystem diversity. This study acknowledges the importance of all three levels, but will focus on species diversity component of biodiversity. As a habitat supports more unique species, the species diversity will go up. Prairie vegetation is naturally ecologically diverse, with a wide range of plants, from trees, to shrubs, to herbaceous vegetation (FWS, 2011). Similarly, in the United States today, grasslands support over 20 million deer, 500,000 pronghorn antelope, 400,000 elk, and numerous other wildlife species (Ducks Unlimited, 2015). While grasslands and wetlands' species diversity may vary from year to year depending on precipitation and other factors, research has shown than increasing prairie vegetation helps promote species diversity, and subsequently biodiversity. This section will highlight three biodiversity benefits of prairie vegetation: benefits for the meadowlark, pollinators, and migratory bird species.

Prairie vegetation has the ability to benefit a number of species, including the Western Meadowlark and pollinators. The Western Meadowlark, North Dakota's state bird, has been experiencing a decline in population, and was recently added to the list of Species of Conservation Priority (Wilson, 2014). Meadowlarks thrive in grassland habitats and enjoy open grasslands, prairie, meadows, and some agricultural fields (Lanyon, 1994). Sandra Johnson, a biologist for the North Dakota Game and Fish, states "If we continue to lose more and more grass in North Dakota, then we are going to see fewer and fewer meadowlarks (Wilson, 2014)." Since the CNS invests in over 1,000 acres of prairie vegetation, it may be a viable solution to help increase Western meadowlark populations.

Similarly, prairie vegetation can provide habitat for pollinators, such as butterfly's and bees. These species provide important services to their local habitat, and are considered vital for 35% of the world's agriculture production. A recent study conducted determined bees are responsible for up to $2.4 billion in annual crop production in California (NRCS, 2013). Additionally, bees and other pollinator species assist in pollinating aesthetically pleasing wildflowers and sunflowers. By creating additional habitat for pollinators, added social and economic benefit can be realized.

There is a robust understanding of the benefits grasslands and wetlands have on migratory bird populations. According to Kirby et al. (2002), "The Prairie Pothole Region comprises only about 10% of North America's wetland breeding area, but produces nearly 50% of the waterfowl in any given year (p.22)". While these benefits can be seen through increased coverage of prairie vegetation and grasslands, there is a clear consensus among scholars that habitat fragmentation does negatively affect migratory bird populations.

Herkert (1994) indicates a large number of grassland birds avoid small grassland fragments, due to the difficulty and limitations these lands have for the majority of grasslands birds. Greenwood et al., (1994) determined bird nests in smaller areas of grassland habitat are at a higher risk of predation than nests in larger un-fragmented areas of land. Overall, three factors have been identified that influence breeding bird populations within these biomes: availability of breeding habitat, reproductive failure, and overwinter mortality (Temple, 1988). When applying this knowledge to the case-study community, it is clear some species of migratory birds may struggle to flourish within some of the more fragmented identified lands in Figure 1.1.

However, despite this consideration, it is understood the loss of grassland habitat is considered one of the most serious conservation problems facing migratory bird species in North America (Noss & Murphy, 1995), and a number of scientists have identified urbanization and agriculture development have significantly contributed to Midwestern grassland bird declines (Herkert 1991; Mayfield 1989, Sample 1989; Warner 1994). After an examination of the urban effects on native bird species, Chace and Walsh (2006) concluded that as “urban areas reinvest and retain native vegetative characteristics, these areas also retain more native species than those that do not.” Similarly, Clergeau et al., (2002) determined, at a regional and local scale, urban bird populations “are independent of the bird diversity of adjacent landscapes.” This indicates localized features are more important than surrounding landscapes. They conclude site-specific initiatives, such as increasing vegetation cover and diversity, can positively alter the bird diversity within the community. This study went on to state there are clear benefits of localized conservation efforts that can improve biodiversity, particularly within local bird populations, and habitat areas within urban communities. It is clear that while some bird species may not directly benefit from the addition of prairie vegetation, the adaptation of this system in Fargo, North Dakota will still benefit local fauna.

### *Water*

Prairie vegetation can be situated on a range of topographies, from uplands to wetlands, and along riparian areas. When situated within a watershed or near a water source, this vegetation may act as a water filter. Similar to how prairie vegetation sequesters carbon, the vegetation soaks up excess metals and nutrients in the plant tissue (Kirby et al., 2002). This action prevents pollutants from incorporating into runoff or entering urban watersheds.

Similarly, prairie vegetation has been noted to provide effective flood attenuation through intercepting flood waters. A familiar natural disaster for the Red River Valley, floods occur sporadically, inundating critical habitat and infrastructure for unpredictable periods of time. According to the Army Corps of Engineers (1994), if previously drained prairie wetlands in the Mississippi River Basin were to be restored, flood peaks could be reduced by 10 to 23% for larger wetlands and 5 to 9% for smaller wetlands. While it is clear the application of prairie vegetation within the CNS would not solve for mitigating the impacts of floods entirely, it could be one tool of many used to promote resilience in approaching the unknown future.

### *Aesthetic Value*

A growing movement within urban landscape architecture is to design with nature in mind. This revitalization can be seen across the United States, where numerous homeowners and communities are pivoting from typical lawn cover, Kentucky bluegrass, to a more natural landscape. This movement has helped reintroduce biodiversity into urban communities, which provides a host of benefits (Priego, Breuste & Rojas, 2008).

Due to the subjective nature of this ecosystem service, less is known on the exact benefits increased aesthetic value can achieve (Chan et al., 2012). Studies have shown the significance of having a "sense of place," and can be considered an effective emotional bond that bridges individuals and natural areas (Altman and Low, 1992; Feldman, 1990; Norton and Hannon, 1997). Additionally, it has been determined people have spiritual, educational, emotional, and physical relationships towards the urban outdoor environment (Millennium Ecosystem Assessment, 2003). Chiesura (2004) indicated cultural ecosystem services include physical and mental health.

This study looks to six dimensions of wellness to actualize the aesthetic benefits of prairie vegetation. According to Hettler (1976), there are six dimensions of wellness: occupational, physical, emotional, spiritual, intellectual, and social. The two dimensions that may relate most to the aesthetic value benefit are the physical and emotional dimensions. The physical dimension acknowledges the need for physical activity and engagement, and the emotional dimension recognizes awareness and acceptance of one's feelings (Hettler, 1976).

Through researching running (Fellin, Manal & Davis, 2010) and cycling (Jobson et al., 2007), studies have shown there is an added benefit to exercising and enjoying the outdoors. When approaching indoor vs outdoor exercise, individuals tend to gain a more productive workout while exercising in the outdoors (Kerr et al., 2012). These studies found that across age groups, individuals are more likely to push themselves further and finding more enjoyment when exercising outdoors.

Similarly, a study that examined how volunteers felt after walking equal distances on a treadmill and outdoors discovered almost all participants reported enjoying the outdoor activity more. In fact, in psychological tests, the participants scored significantly higher on "measure of vitality, enthusiasm, pleasure and self-esteem, and lower on tension, depression and fatigue after they walked outside (Thompson et al., 2011)."

Clearly, there is an added benefit of experiencing and enjoying the outdoors. An increase of mental and physical health has a multitude of additional benefits that can possibly boost other areas of wellness, like intellectual and spiritual (Reynolds, 2013). While more could be understood on how aesthetic values objectively affect individuals, it is easy to infer how communities can benefit from more access to natural areas.

With the CNS applied to the case-study area of Fargo, North Dakota, four land use benefits can be achieved. The prairie vegetation can effectively sequester carbon emissions, provide habitat for important wildlife and pollinators, while resiliently filtering water. Prairie vegetation may provide aesthetic benefits that promote mental and physical health. Next, this chapter will discuss the composition and uses of biochar.

## Biochar

The recent attention and research interest on biochar may lead an individual to think this is an emerging biotechnology, but biochar has existed for centuries. Dating back to the Neolithic area to early agriculture activities, biochar or biochar-like products were used to increase the soil organic content (Lehmann & Joseph, 2015). These processes have been documented by scientists across the world. In Asia (Sheil et al., 2012) and Japan (Ogawa and Okimori, 201), early uses of biochar were documented as a soil amendment for rice fields.

Medieval cultures utilized ash as amendment to composting processes (Muckenhausen et al., 1968; Holliday, 2004). In Australian, several soils indicate to being developed by aboriginal oven mounds, the depris of which increased the soil organic material (Coutts et al., 1976). According to Coutts et al. (1976), these soils resembled the most notable Amazonian Dark Earth soils, with their high nutrient and C contents.

Some of the earliest and most notable uses of biochar date back to Central Amazonia. These 8,000-year-old-man-made soils are known as Anthropogenic Dark earths or *Terra preta de Indio (Terra Preta)* (Shackley et al., 2016). According to Glaser and Birk (2012), these soils were constructed through the collection of large amounts of kitchen leftovers, excrements, biomass waste and charred residue. This land was more productive due to its high carbon content and increased organic material. Glaser et al. (2001) noted *Terra Preta* sites had been enriched by a factor of 70 compared to adjacent, untreated soils. The benefits of biochar as a soil amendment date back to the dawn of agriculture, and is one of the most studied areas of biochar today. How these benefits are realized can be further understood by examining the composition and production of biochar.

### *Composition and Production*

The composition and characteristics of biochar are dependent on a multitude of variables, including the cellular structure of the initial organic material, or feedstock, its chemical composition, and how the biochar is processed (Lehmann & Joseph, 2015). For example, when grasses and leaves are processed into biochar, their biochar product resembles their unique cellular structures, maintaining a similar shape. This creates high levels of microporosity, containing pores with diameters less than 2nm, within the biochar product. With high microporosity, biochar can lock nutrients and chemicals into its structure like a sponge.

For example, if the prairie vegetation used for the feedstock was exposed to high levels of phosphorus (P), the biochar product will then contain high levels of P within its chemical composition. These physical and chemical properties work to benefit as a soil amendment, naturally increasing the soil organic content and, in this example, phosphorus content. It is easy to understand how the physical and resulting chemical characteristics of biochar are the cornerstones to the numerous benefits of the biochar product.

Another factor in the variability of biochar is how it is produced. Biochar can be produced through a number of different pyrolysis techniques, including: slow, fast, intermediate, microwave, flash, and vacuum pyrolysis. This study focuses on slow-pyrolysis methods, as depicted in Figure 1.2, since it is the method applied to the CNS. As defined by Shackley et al. (2016), “pyrolysis is a process of thermal decomposition of carbonaceous organic materials in the complete or nearly complete absence of oxygen (p. 22).”

Slow pyrolysis differs from other methods as it is characterized by a low heating rate and longer processing time (Shackley et al., 2016). In Figure 1.2, biomass enters the feed hopper, and is then transferred to the oven through an auger system. Here, indirect heat is applied and the water content of the organic material is removed. Gasification occurs at this stage while the organic material is baked at 1000°F, converting the biomass into biochar. The biochar is then transported into a cooling chamber before it is placed into a storage container. While slow pyrolysis can take from tens of minutes to several days, this process produces some of the highest biochar yields (Lehmann & Joseph, 2015). Due to the simplicity and yield of the slow-pyrolysis method, it is best suited to the applied within the CNS.

The slow-pyrolysis method has two beneficial outputs: syngas and the biochar product. Syngas is produced through the gasification processes, and can be utilized as a biofuel. According to Mackaluso (2007), syngas used within combustion engines is an environmentally sustainable alternative to imported petroleum fuels, and has the potential to reduce the impacts of greenhouse gasses. Applying this benefit to the city of Fargo could utilize syngas in municipal busses. Since the syngas is a byproduct of the biochar process, this benefit could greatly reduce fuel and transportation expenses for the community. Similarly, the biochar product can either be sold or used municipally in a variety of ways. This study acknowledges the array of benefits that can be realized from biochar, and will focus on the possible benefits of utilizing biochar as a soil amendment.

### ***Land Application***

Just as the characteristics of biochar are dependent on the feedstock and pyrolysis method, the benefits of biochar as a soil amendment also depends on the soil characteristics where it is applied. Overall, biochar may have an effect on the nutrient availability, hydrology, and microorganism habitat. Similar to the important role soil organic matter has on soil processes, biochar has some comparable effects on these processes, “but the magnitude and dynamic of these effects is often different (Shackley et al., 2016, p. 93).”

In order for crops and plants to grow, the soil must provide available nutrients to the vegetation. Vegetation can obtain nutrients from the soil through three methods: directly from organic material, pH buffering capacity and cation exchange capacity (CEC) (Lehmann & Joseph, 2015). This study will focus on the effects biochar may have on the CEC, in addition to how biochar may effect water retention and quality. The CEC is the total capacity of a soil to hold exchangeable cations, and organic matter has a higher CEC than many soils particles. With a high CEC, plants can take up nutrients through mineralized salts and the interaction between positively and negatively charged ions within the soil.

Since plants can only take up nutrients through mineralized salts, the relationship between the soil's positively charged ions and organic material is incredibly important. The mineralized salts contain positively charged ions including: sodium ($Na^+$), potassium ($K^+$), calcium ($Ca^{++}$), magnesium ($Mg^{++}$), and ammonium ($NH_4^+$). The soil organic matter and clay materials contain negatively charged ions that can attract the mineralized salts. When metal ions and organic molecules combine, chelates are formed. Chelates assist micronutrients (e.g. iron, zinc, copper) in becoming more soluble, helping the plant in absorbing these nutrients (Shackley et al., 2016).

While the CEC of biochar is low, research has indicated the CEC of biochar may increase over time (Glaser et al., 2001). Biochar may have the capacity to gradually increase the soil CEC overtime, effectively providing more nutrients to the local vegetation. As illustrated in Figure 2.2, overtime a small amount of biochar was incorporated into the flowerpot on the left, whereas the right flowerpot was left untreated. This evidence may represent a visual depiction of the biochar increasing the CEC of the soil, providing more nutrient excess for the flowers. It is suggested with the added availability of nutrients, biochar may assist in the biodiversity and habitat for soil microorganisms (Shackley et al., 2016)

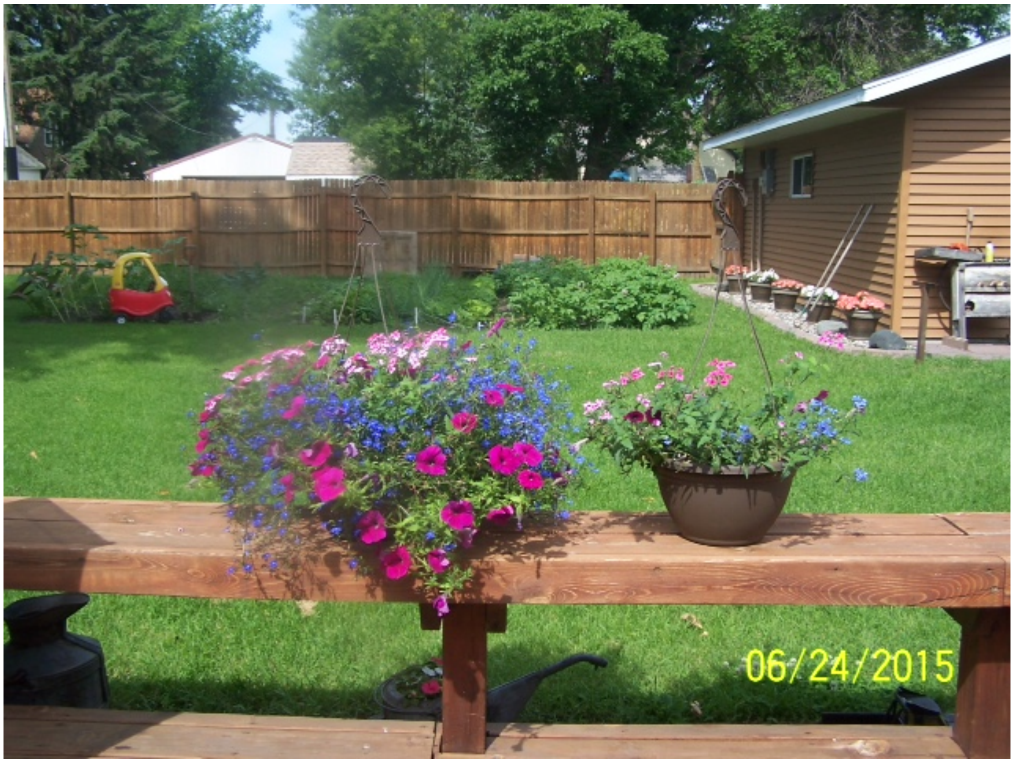

*Figure 2.2.* Effects of Biochar on Household Flowers. Source: Borchert, 2016

Studies have shown biochar also has the ability to positively benefit the soil hydrology. The swelling and shrinking properties of soil organic content lie in the soil porosity. Kinney et al. (2012) determined biochar can hold up to 11 times its own mass of water. While this number is lower than compared to soil organic matter, applying biochar to the soil has shown an increase in water holding capacity, depending on the soil type (Lehmann & Johnson, 2015). Additionally, Laird et al. (2010) determined biochar was beneficial in Midwestern soils, noting biochar as a soil amendment can be an effective management strategy to reduce nutrient leaching.

Due to the robust knowledge on the benefits and capacity of soil organic carbon, comparisons and similarities can be drawn to using biochar in land applications. A large number of studies show significant agriculture benefit in using biochar, but a small number of studies do show no significance (Sohi, Bol & Lopez-capel, 2009). This variability may be the result of the range of properties biochar may possess, as well as the local soil characteristics (Shackley et al., 2016). Currently, more research is needed to determine the predictive capacity of biochar, so more can be understood on how to best optimize production and performance (Sohi, Bol & Lopez-capel, 2009). It is understood the soil organic material has a tremendous effect on the availability of nutrients and water holding capacity of the soil, but more needs to be understood on the specific benefits biochar may have.

When applied to the CNS, a range of benefits may be realized municipally as well as economically. The City of Fargo could potentially utilize biochar as a soil amendment on community garden spaces, within parks and recreation areas, or municipally through water filtration practices. Generally, for every unit of feedstock used for biochar 0.6 units of biochar is produced. Table 2.1 addresses how much biochar could be produced if the CNS were to be applied to Fargo's 1,000 acres of underutilized lands

Additionally, large quantities of underutilized organic materials remain unused at the landfill (P. Hanson, personal communication, March 12, 2016), which could equal up to 12,000 tons (10,886 Tonnes) of biochar. This totals the potential annual biochar production to 15,000 tons (13,608 Tonnes). The economic and municipal benefits of the biochar produced by the system are further explored later in this chapter.

Table 2.1
*Biochar Produced from the Carbon Negative System Annually*

| **Feedstock** | **Conversion to Biochar** | **Total annual production (Prairie Vegetation based on 1000 Acres)** |
|---|---|---|
| **Prairie Vegetation** | 5 tons (4.5 tonnes) vegetation to 3 tons (2.7 tonnes) biochar | 3,000 tons ( 2,722 tonnes) |
| **Biochar from Landfill Materials** | 20,000 tons (18,143 Tonnes) to 12,000 tons (10,886 Tonnes) biochar | 12,000 tons (10,886 Tonnes) |
| **Total Annual Biochar Produced** | | 15,000 tons (13,608 Tonnes) |

## Carbon Budget

To determine whether a true carbon benefit is achieved with the CNS, a carbon budget was constructed. The carbon outputs considered were: planting, harvest, transportation, the biochar process, and traditional mowing. Additionally, the carbon sequestration capacity of prairie vegetation was analyzed. As depicted in Table 2.2, the CNS effectively sequesters carbon emissions.

First, it is important to consider the existing carbon outputs and sequestration capacity. Currently, it is estimated the City of Fargo produces 48 kg C per year through the traditional mowing practices (Government of Canada, n.d.). However, since prairie vegetation lacks the need for mowing, this carbon output is eliminated within the CNS. While this process will be removed with the system, there are other carbon costs to consider.

Planting the prairie vegetation occurs once and produces 6.79 kg C/ha/year (West & Marland, 2002). The annual harvest produces 16.47 kg C/ha/year, while the transportation of the harvested material to the landfill produces 125.92 kg C/ha/year. These carbon outputs total to 1430.69 kg C/ha produced throughout the 10-year period.

Prairie vegetation has the capacity to effectively sequester carbon through soil carbon storage. How much carbon prairie vegetation can sequester has been noted to vary. Prairie carbon storage rates have been noted to vary from .30 (Rice, 2002) to 1.7 (Garcia-Alvarez, 2011) metric tons per acre per year. When converting cropland to CRP, a cost-share and rental payment conservation program under the United States Department of Agriculture to improve environmental quality (USDA, n.d.), a study found an increase of 0.50 Mg/ha/year in carbon sequestration (Gascoigne et al., 2011).

Another study indicated that grassland biomes sequestered carbon more effectively than forest, desert, rain forest, or shrubland, improving rates of 0.35 kg C/ha/year (Conant, Paustain & Elliot, 2001). McCulley (2011) applied this analysis to healthy midwest tallgrass prairies, and found the capacity to sequester 2 x $10^3$ kg C/$ha^2$/year, but a more commonly referenced study indicated the mean annual carbon accumulation rate of prairie vegetation can range from 16.3 g to 12.3 g C/$m^2$ (Cahill et al., 2009). This study assumes prairie vegetation has the carbon sequestration capacity of 20 g C/$m^2$/year. As indicated in Table 2.1, this capacity converts to 200 kg C/ha/year. Comparing this capacity to the planting (6.79 kg C/ha/year), harvesting (16.37 kg C/$ha^2$/year) and transportation (125.92 kg C/ha/year), it is easy to infer how this system results in a net benefit of carbon sequestration due to the effective carbon storage properties of prairie vegetation (West & Marland, 2002).

Finally when considering the potential carbon outputs or inputs with the biochar processing facility, it is important to note its sustainable design. The CNS highlights the biochar processing facility could ideally be a self-sustaining system if it is powered by the excess methane from the city landfill. According to landfill officials, there is a virtually unlimited supply of methane produced by the natural decomposition processes at the landfill. The landfill officials are constantly exploring new and innovative ways to harness this energy, preventing the methane from entering the atmosphere. The CNS suggests utilizing these excess methane as the power source for the biochar facility, suggesting the facility should theoretically produce little to zero carbon emissions. By using methane as the power sources the biochar production can be carbon neutral, while preventing methane from entering the atmosphere.

Table 2.2
*Carbon Budget for 10 Year Period*

| ***Carbon Emitted*** | **kg C/ha/year** | **Occurrence** | **kg C/ha/10 year** | **Source** |
|---|---|---|---|---|
| *Planting* | 6.79 | 1x | 6.79 | (West & Marland, 2002) |
| *Harvest* | 16.47 | Annually | 164.7 | (West & Marland, 2002) |
| *Transportation* | 125.92 | Annually | 1259.2 | (West & Marland, 2002) |
| ***Biochar Process*** | 0 | Annually | 0 | (C. Borchert, personal communications, January 12, 2016) |
| ***Carbon Sequestered*** | | | | |
| *Prairie Vegetation* | 200 | Annually | 2,000 | (Cahill et al., 2009) |
| *Total Net Carbon Sequestration (NCS) (20% Contingency Factor)* | Total NCS: **569.3** kg C/ha/10 years = 2000-1259.2-164.7-6.79<br>High NCS (+20%): **969.3** kg C/ha/10 years = 2400-1259.2- 164.7-6.79<br>Low NCS (-20%): **169.3** kg C/ha/10 years = 1600-1259.2-164.7-6.79 | | | |
| ***Carbon Emitted Without Carbon Negative System*** | | | | |
| *Traditional Mowing* | 480 | Annually | 4,800 | (Government of Canada, n.d.) |

The total net carbon sequestration of this system is nearly equivalent to the prairie vegetation's carbon sequestration (569.3 kg C/ha/10 years), further exemplifying the total net carbon sequestration benefit. To account for the variance in the vegetation's carbon sequestration capacity, a twenty percent (20%) contingency calculation was made. This indicates a reasonable range of carbon sequestration power from 169.3 – 969.3 kg C/ha/10 years. The CNS can compensate for the carbon emissions generated within the system, and has the capacity to effectively sequester additional carbon emissions. The remainder of this chapter explores the financial and economic factors of the CNS.

## Economic Analysis

To paint a picture of the financial feasibility of the system, an economic analysis was conducted. Economic analysis can be utilized to understand the financial and economic implications of a proposed project. However, due to the limitations of this study and the natural limitations of economic analysis, it is understood projections and forecasting cannot be considered an exact science. For these reasons, the majority of this section focuses on the variability and sensitivity of the estimated costs and benefits of the CNS as it is applied to Fargo, North Dakota. This section includes the cost benefit analysis, return on investment, sensitivity, and overall costs and income of the proposed system within the scope of Fargo, North Dakota.

Two scenarios were constructed to analyze the system. The first scenario, "Biochar Markets," depicts the City of Fargo using biochar municipally in addition to entering biochar markets. Biochar markets are considered emerging and vary in pricing (Shackley et al., 2016). Therefore, this study accounts for this variability in a sensitivity analysis later on in this section. The Biochar Markets scenario assumes the City of Fargo will sell biochar at two different price levels, regular pricing and bulk pricing. This study assumes roughly 4,000 tons will be sold at regular pricing ($250/ton), and 7,000 tons will be sold in bulk pricing ($200/ton). Finally, this scenario assumes 4,000 tons of biochar are utilized municipally.

The second scenario is “Municipal Use,” where the City of Fargo forgoes entering the emerging biochar markets, and instead uses roughly 4,000 tons of biochar municipally. All other variables are similarly weighed in both scenarios. The main difference between the two scenarios is whether or not the City of Fargo engages in the emerging biochar markets. The next section determines the cost benefit analysis, in addition to the sensitivity analysis for a range of variables.

### ***Cost Benefit Analysis***

A Cost Benefit Analysis was conducted for both scenarios to further detail the line items associated with the CNS. In Table 2.1 and Table 2.2, the costs and revenues associated with each scenario are listed. Net Present Value was calculated using a five percent discount rate. Both the Biochar Markets and Municipal Use Scenarios have the same Net Present Value (NPV) Costs at -$18,329,486. Where the scenarios differ is in the income generated.

The Biochar Markets generates a total NPV Income of $23,841,607 and a Return on Investment (ROI) of 0.30. In contrast, the Municipal Use scenario generates a total NPV Income of $9,690,179 and a ROI of -0.47. This section will explore how each of these variables were determined and identified the sensitivity of these figures. Tables 2.3 and 2.4 indicate the cost benefit analysis for both scenarios. Finally, it is important to note both analyses are based on the utilization of 1,000 acres of public lands.

Table 2.3

*Biochar Markets Scenario Cost Benefit Analysis*

| **Costs** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
|---|---|---|---|---|---|
| **Facility Construction** | -$15,000,000 | $0 | $0 | $0 | $0 |
| **Facility Operations** | $0 | -$253,440 | -$253,440 | -$253,440 | -$253,440 |
| **Harvest** | $0 | -$100,000 | -$100,000 | -$100,000 | -$100,000 |
| **Seeding** | -$300,000 | $0 | $0 | $0 | -$50,000 |
| **Subtotals of Costs** | -$15,300,000 | -$353,440 | -$353,440 | -$353,440 | -$403,440 |
| **NPV of Costs** | **-$15,300,000** | **-$336,610** | **-$336,610** | **-$336,610** | **-$384,229** |

| **Income** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
|---|---|---|---|---|---|
| **Maintenance Savings** | $93,750 | $93,750 | $93,750 | $93,750 | $93,750 |
| **Biochar Sales (non-bulk)** | $0 | $1,000,000 | $1,000,000 | $1,000,000 | $1,000,000 |
| **Biochar Sales (bulk)** | $0 | $1,400,000 | $1,400,000 | $1,400,000 | $1,400,000 |
| **Municipal Biochar Use** | $0 | $251,000 | $251,000 | $251,000 | $251,000 |
| **Carbon Credit Sales** | $0 | $1,122,680 | $1,122,680 | $1,122,680 | $1,122,680 |
| **Grants and Seed Money** | $0 | $0 | $0 | $0 | $0 |
| **Existing Funds** | $50,000 | $0 | $0 | $0 | $0 |
| **Subtotal of Income** | $143,750 | $3,867,430 | $3,867,430 | $3,867,430 | $3,867,430 |
| **NPV Income** | **$143,750** | **$3,683,267** | **$3,683,267** | **$3,683,267** | **$3,683,267** |

| | | | | | |
|---|---|---|---|---|---|
| **NPV Revenues** | **-$15,156,250** | **-$11,809,593** | **-$8,462,936** | **-$5,116,279** | **-$1,817,240** |

Table 2.4

*Municipal Use Scenario Cost Benefit Analysis*

| **Costs** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
|---|---|---|---|---|---|
| **Facility Construction** | -$15,000,000 | $0 | $0 | $0 | $0 |
| **Facility Operations** | $0 | -$253,440 | -$253,440 | -$253,440 | -$253,440 |
| **Harvest** | $0 | -$100,000 | -$100,000 | -$100,000 | -$100,000 |
| **Seeding** | -$300,000 | $0 | $0 | $0 | -$50,000 |
| **Subtotals of Costs** | -$15,300,000 | -$353,440 | -$353,440 | -$353,440 | -$403,440 |
| **NPV of Costs** | **-$15,300,000** | **-$336,610** | **-$336,610** | **-$336,610** | **-$384,229** |

| **Income** | **Year 1** | **Year 2** | **Year 3** | **Year 4** | **Year 5** |
|---|---|---|---|---|---|
| **Maintenance Savings** | $93,750 | $93,750 | $93,750 | $93,750 | $93,750 |
| **Municipal Biochar Use** | $0 | $1,000,000 | $1,000,000 | $1,000,000 | $1,000,000 |
| **Carbon Credit Sales** | $0 | $1,122,680 | $1,122,680 | $1,122,680 | $1,122,680 |
| **Grants and Seed Money** | $0 | $0 | $0 | $0 | $0 |
| **Existing Funds** | $50,000 | $0 | $0 | $0 | $0 |
| **Subtotal of Income** | $143,750 | $2,216,430 | $2,216,430 | $2,216,430 | $2,216,430 |
| **NPV Income** | **$143,750** | **$2,110,886** | **$2,110,886** | **$2,110,886** | **$2,110,886** |

| | | | | | |
|---|---|---|---|---|---|
| **NPV Revenues** | **-$15,156,250** | **-$13,381,974** | **-$11,607,698** | **-$9,833,421** | **-$8,106,764** |

***System Expenses & Sensitivity Analysis***

**Facility Cost** - The facility costs estimated for both scenarios was $15 million dollars. Since there is not an industrial-level biochar facility to model (Shackley et al., 2016), this cost was speculated after researching charcoal pelletizing facility costs. Table 2.5 and 2.6 explore the sensitivity of the facility cost as it ranges from $5 million to $25 million.

Table 2.5

*Facility Cost Sensitivity Analysis for Biochar Markets Scenario*

| **Facility Cost** | **$5 million** | **$10 million** | **$15 million** | **$25 million** |
|---|---|---|---|---|
| **Total NVP Costs** | -$8,329,486 | -$13,329,486 | -$18,329,486 | -$28,329,486 |
| **Total NPV Income** | $23,841,607 | $23,841,607 | $23,841,607 | $23,841,607 |
| **ROI for 10 Years** | 1.86 | 0.79 | 0.30 | -0.16 |
| **Break Even Point** | Year 4 | Year 6 | Year 8 | > Year 10 |

Table 2.6

*Facility Cost Sensitivity Analysis for Municipal Use Scenario*

| **Facility Cost** | **$5 million** | **$10 million** | **$15 million** | **$25 million** |
|---|---|---|---|---|
| **Total NPV Costs** | -$8,329,486 | -$13,329,486 | -$18,329,486 | -$28,329,486 |
| **Total NPV Income** | $9,690,179 | $9,690,179 | $9,690,179 | $9,690,179 |
| **ROI for 10 Years** | 0.16 | -0.27 | -0.47 | -0.66 |
| **Break Even Point** | Year 9 | > Year 10 | > Year 10 | > Year 10 |

When a sensitivity analysis for the facility construction costs was conducted, the total NPV income was the same for both scenarios, as depicted in the tables above. The NPV costs ranged from -$8,329,486 to -$28,329,486 depending on if the annual facility costs. For the Biochar Markets scenario, the return on investment ranged from 1.86 to -0.16, and the break even point ranged from Year 4 to greater than Year 10.

The Municipal Use scenario exhibited a range of ROI at 0.16 to -0.66, and break even points ranging from Year 9 to greater than Year 10. It will be important to consider as the facility costs for both scenarios, as the ROI can fluctuate and the break-even point has the capacity to shift past the ten-year mark.

**Facility Operations** – The facility operations expense utilized existing research on the value chain analysis on wood pelletizing production. According to Qian and McDow (2013), the plant operation costs of producing wood pellets can range from \$21.12/ton to \$131.19/ton. Considering the sustainability and pre-existing infrastructure, this analysis assumes the lowest cost for the facility operations expenses, totaling to \$253,440 annually. Tables 2.7 and 2.8 explore the sensitivity of these costs, ranging from \$100,000 to \$350,000, annually.

Table 2.7
*Facility Operations Cost Sensitivity Analysis for Biochar Scenario*

| **Facility Operations Costs** | **\$100,000** | **\$253,440** | **\$350,000** |
|---|---|---|---|
| **Total NVP Costs** | -\$17,014,286 | -\$18,329,486 | -\$19,157,143 |
| **Total NPV Income** | \$23,841,607 | \$23,841,607 | \$23,841,607 |
| **ROI for 10 Years** | 0.40 | 0.30 | 0.25 |
| **Break Even Point** | Year 8 | Year 8 | Year 8 |

Table 2.8
*Facility Operations Cost Sensitivity Analysis for Municipal Use Scenario*

| **Facility Operations Costs** | **\$100,000** | **\$253,440** | **\$350,000** |
|---|---|---|---|
| **Total NVP Costs** | -\$17,014,286 | -\$18,329,490 | -\$19,157,143 |
| **Total NPV Income** | \$9,690,179 | \$9,690,179 | \$9,690,179 |
| **ROI for 10 Years** | -0.43 | -0.47 | -0.49 |
| **Break Even Point** | > Year 10 | > Year 10 | > Year 10 |

For this sensitivity analysis, the total NPV income was the same for both scenarios, as depicted in the tables above. The NPV costs ranged from -\$17,014,286 to -\$19,157,143 depending on if the annual facility operations cost. For the Biochar Markets scenario, the return on investment ranged from 0.40 to 0.25, and the break even point remained at Year 8 throughout the analysis. The Municipal Use scenario exhibited a range of ROI at -0.43 to -0.49, and break even points remained at greater than ten years. It will be important to consider as the facility costs for both scenarios, as the ROI can fluctuate and the break-even point has the capacity to shift past the ten-year mark.

**Harvest & Transportation** – This figure was calculated to consider the majority of expenses affiliated with the harvesting practice of this system within the scope of the geographic area of Fargo. According to Iowa State University (2016), an extension economist for the United States Department of Agriculture, bailing hay and labor costs equate to \$100,570 annually, accounting for the cost of gasoline, machine use, transportation, and employee time.

More specifically, it costs roughly \$65,000 in harvest related expense including combine maintenance and fuel. Additionally, it costs roughly \$35,000 to transportation expenses, including the vehicle maintenance and fuel. This analysis assumes \$100,000 in annual costs for the total harvesting process. A sensitivity analysis was not conducted for this variable.

**Seeding the Land** – According to Prairie Restoration Incorporated (2013), for this case-study it would cost over \$3 million dollars to convert 1000 acres of underutilized land into prairie vegetation. Conversely, according to Aakre (2013), an agriculture economist at North Dakota State University estimates the cost of bailing and harvesting to range between \$0.40 - \$10.00 a bail, which equates to approximately \$15,000 of annual costs for this system. Understanding the variability of this expense, this study assumes \$300,000 for the initial seeding cost with a reoccurring expense of $50,000 for adaptive management practices. Additionally, the sensitivity analysis below looks at this range of costs from $20,000 to $2,500,000 for the system, as indicated in Table 2.9 and Table 2.10.

Table 2.9
*Seeding Cost Sensitivity Analysis for Biochar Markets Scenario*

| **Seeding Costs** | **$20,000** | **$100,000** | **$300,000** | **$2.5 million** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,049,486 | -$18,129,486 | -$18,329,486 | -$20,529,486 |
| **Total NPV Income** | $23,841,607 | $23,841,607 | $23,841,607 | $23,841,607 |
| **ROI for 10 Years** | 0.32 | 0.32 | 0.30 | 0.16 |
| **Break Even Point** | Year 8 | Year 8 | Year 8 | Year 9 |

Table 2.10
*Seeding Sensitivity Analysis for Municipal Use Scenario*

| **Seeding Costs** | **$20,000** | **$100,000** | **$300,000** | **$2.5 million** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,049,486 | -$18,129,486 | -$18,329,486 | -$20,529,486 |
| **Total NPV Income** | $9,690,179 | $9,690,179 | $9,690,179 | $9,690,179 |
| **ROI for 10 Years** | -0.46 | -0.47 | -0.47 | -0.53 |
| **Break Even Point** | > Year 10 | > Year 10 | > Year 10 | > Year 10 |

The sensitivity analysis conducted for the seeding cost, as depicted in Tables 2.9 and 2.10, determined a constant NPV income of $23,841,607 and $9,690,179 for the Biochar Market and Municipal Use scenarios, respectively. For the Biochar Markets Scenario, the total NPV costs ranged from -$18,049,486 to -$20,529,486, while the ROI ranged from 0.32 to 0.16. Additionally, the break-even point remained at Year 8 until the seeding cost was raised to $2.5 million, where the break-even point shifted to Year 9.

For the Municipal Use Scenario, the same range of costs were exhibited and the ROI ranged from -0.46 to -0.53. The break even point remained past year Year 10. It is clear with increasing seed costs, there will be a more dramatic effect on the Municipal Use scenario than on the Biochar Markets scenario.

***System Income and Benefits***

**Maintenance Saving** – Mowing and maintain these underutilized lands can be calculated as a large cost sink for the City of Fargo. According to City of Fargo public officials the city spends \$37.50/hour to mow eight acres a land per hour, which includes fuel, equipment maintenance and cost, and operation expenses (Dow, 2016). Additionally, the city may mow these lands up to twenty times a year, depending on the seasonal precipitation. Applying these figures to the 1000 acres of underutilized land in this case-study, the city will save \$4,687.50 every time the city forgoes mowing, equating to an annual savings of \$93,750. A sensitivity analysis was not conducted for this variable.

**Biochar Sales –** Perhaps the most variable item within this cost-benefit analysis, the biochar sales can range anywhere from \$0.13/lbs (TR Miles Technical Consultants, 2016) to \$2.20/lbs (Shackley et al., 2016) after conversions. Both authors contest that these figures can also adjust depending on the quantity of biochar sold. Whether it is due directly to the range of biochar compositions or the emerging biochar markets, it is clear there is little standardization with biochar pricing.

This analysis assumes \$0.13/lbs or \$250/ton for the price of biochar, and indexes both the biochar sales and municipal uses to this figure, equating to \$2,400,000 of annual biochar sales revenues and \$251,000 in biochar benefits in the Biochar Markets Scenario. The annual sales revenues were determined by selling 4,000 tons at \$250/ton, and 7,000 tons at \$200/ton. The biochar benefits were calculated assuming $250/ton for 1,004 tons of biochar used municipally. Considering the variability with the biochar pricing, the sensitivity analysis below (Tables 2.11 and 2.12) investigates the range of prices from $0.13/lb to $2.20/lb for this system.

Table 2.11

*Biochar Value Sensitivity Analysis for the Biochar Markets Scenario*

| **Biochar Value** | **$0.13/lb** | **$0.75/lb** | **$1.50/lb** | **$2.20/lb** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $23,841,607 | $139,259,184 | $286,127,321 | $418,127,321 |
| **ROI for 10 Years** | 0.30 | 6.60 | 14.61 | 22.81 |
| **Break Even Point** | Year 8 | Year 3 | Year 2 | Year 2 |

Table 2.12

*Municipal Biochar Use Sensitivity Analysis for Municipal Use Scenario*

| **Biochar Value** | **$0.13/lb** | **$0.75/lb** | **$1.50/lb** | **$2.20/lb** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $9,690,179 | $50,569,293 | $103,975,893 | $151,975,893 |
| **ROI for 10 Years** | -0.47 | 1.76 | 4.67 | 7.29 |
| **Break Even Point** | > Year 10 | Year 4 | Year 3 | Year 2 |

While the cost-benefit analysis for this study assumed the lowest price point for biochar, the emerging biochar markets indicate a range of prices from $0.13/lb to $2.20/lb worldwide (Tables 2.11 and 2.12). To account for this variance, a sensitivity analysis was conducted to analyze the effects of different biochar prices on both scenarios. The total costs for both scenarios remained the same at -$18,329,486. For the Biochar Markets Scenario, the total income ranged from $23,841,607 to $418,127,321, and the ROI ranged from 0.40 to 22.81. Finally, as the price of biochar increased, the break even point went from Year 8 to Year 2.

For the Municipal Use scenario, the income ranged from $9,690,179 to $151,975,893, and the ROI ranged from -0.47 to 7.29. As the cost of biochar increased, the break-even point went from greater than Year 10 to Year 2. Clearly, the price of biochar has a dramatic effect on both the Biochar Markets and Municipal Use scenarios' income, return on investment, and the break-even points.

**Municipal Use –** It is difficult to quantify all of the municipal uses biochar and syngas have within the city of Fargo. According to a United States Environmental Protection Agency, charcoal filtration systems for municipal water treatment can range in costs from $70,000 to $100,000 (US EPA 2015; 1979) Similarly, with the opportunity to fuel municipal busses and transportation with the syngas from the biochar process, dollars saved in fuel costs could dramatically shift the benefits of this system. By carrying over the market value of $250/ton for biochar, a reference point can be drawn to illustrate the municipal benefits. In the Municipal Uses Scenario, more biochar is used internally, totaling to 4,000 tons of biochar. This equates to $1,000,000 of benefits. The sensitivity of this variable is further demonstrated within the above biochar markets analysis.

**Carbon Credit Sales –** Since there lacks a global carbon credit market, this study looked to the California's Global Warming Solutions Act of 2006 for a current carbon credit index. As of September 29, 2016 carbon credits were indexed at $12.95/Tonne of $CO_2$. The prairie vegetation would sequester carbon at a presumed rate of 200 kg C/ha/year (Cahill et al., 2011). In total, the CNS applied to 1,000 acres in Fargo, ND would sequester 80.9 tons of carbon per year.

Additionally, biochar has the capacity to remain in the soil from decades to millennia, depending on its composition (Shackley et al., 2016). This is effectively another source of carbon sequestration and which can be added to the carbon credits. Since the CNS could produce over 20,000 tons at full capacity, it is reasonable to conservatively estimate that 2,000 tons of biochar is incorporated into the soil in a year resulting in 1,455 tons in sequestered carbon. This figure can be included into the carbon credit sales the City of Fargo engages in for this system. In total, about $20,000 of annual carbon credit sales can be realized with this system at $12.95 a credit (1,544 tons carbon x $12.95, with 89 tons from prairie vegetation sequestration and 1,455 tons from biochar). To account for the variability demonstrated with this figure, a sensitivity analyze tested a range of 10,000, 50,000 and 250,000 tons of sequestered carbon in Tables 13 and 14.

*Table 2.13*
*Carbon Credit Sales Sensitivity Analysis for Biochar Markets Scenario*

| **Tons of Carbon** | **2,000** | **10,000** | **50,000** | **250,000** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $23,841,607 | $24,784,464 | $29,241,607 | $51,441,607 |
| **ROI for 10 Years** | 0.30 | 0.35 | 0.60 | 1.81 |
| **Break Even Point** | Year 8 | Year 8 | Year 7 | Year 4 |

Table 2.14

*Carbon Credit Sales Sensitivity Analysis for Municipal Use Scenario*

| **Tonnes of Carbon** | **2,000** | **10,000** | **50,000** | **250,000** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $9,690,169 | $10,633,036 | $15,090,179 | $37,290,179 |
| **ROI for 10 Years** | -0.47 | 0.42 | -0.18 | 1.03 |
| **Break Even Point** | > Year 10 | > Year 10 | > Year 10 | Year 5 |

For the Biochar Markets Scenario, the NPV Costs remained constant at -$18,329,486, and the NPV Income ranged from $23,841,607 to $51,441,607. This determined a ROI ranging from 0.30 to 1.81, and the breakeven point moved from Year 8 to Year 4. The Municipal Use Scenario demonstrated the same costs, and had NPV Income range from $9,690,169 to $37,290,179. The ROI ranged from -0.47 to 1.03, and the break even point moved to Year 5 for the 250,000 Tonnes of Carbon analysis.

Depending on the total Tonnes of Carbon sequestered, a carbon credit market has the potential to dramatically impact the revenues of this system. Additionally, it is important to note the carbon credit market may fluctuate in value, creating additional uncertainty with the variable. With the establishment of a national carbon credit market, a greater understanding of the implications and impacts of this system can be realized.

**Grants and Seed Money –** This study did not assume an amount for grant or seed money to abate the initial costs of the system. While a wealth of federal and state grants may be obtained for the implementation of this system, this study only assumed the existing City of Fargo funding of $50,000 for landfill expansions (P. Hanson, personal communication, March

12, 2016). However, a sensitivity analysis in this section indicates how varying amounts of start-up dollars will affect both scenarios, as illustrated in Tables 2.15 and 2.16).

Table 2.15
*Grant and Seed Benefit Sensitivity Analysis for Biochar Markets Scenario*

| **Grant/Seed Total** | **$0** | **$5 million** | **$10 million** | **$20 million** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $23,841,607 | $28,841,607 | $33,841,607 | $43,841,607 |
| **ROI for 10 Years** | 0.30 | 0.57 | 0.85 | 1.39 |
| **Break Even Point** | Year 8 | Year 6 | Year 4 | Year 1 |

Table 2.16
*Grant and Seed Benefit Sensitivity Analysis for Municipal Use Scenario*

| **Grant/Seed Total** | **$0** | **$5 million** | **$10 million** | **$20 million** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $9,690,179 | $14,690,179 | $19,690,179 | $29,690,179 |
| **ROI for 10 Years** | -0.47 | -0.20 | 0.74 | 0.62 |
| **Break Even Point** | > Year 10 | > Year 10 | Year 9 | Year 1 |

Since there are federal and state funds that could be applied to the construction of the CN system, a sensitivity analysis was conducted for both scenarios, Tables 2.15 and 2.16, to investigate the impacts of grant and seed money ranging from $0 to $20 million. Costs remained constant for both scenarios at -$18,329,486. For the Biochar Markets scenario, the total NPV income ranged from $23,841,607 to $43,841,607 and the ROI ranged from 0.30 to 1.39. As the investment dollars increased, the break-even point went from Year 8 to Year 1.

The total NPV income for the Municipal Use scenario ranged from $9,690,179 to $29,690,179, and the ROI ranged from -0.47 to 0.62. As the initial investment increased, the break-event point went from great than Year 10 to Year 1. With additional income for the system development, a dramatic impact on the income, return on investment, and break even point exists for both scenarios.

**Existing Funds for Land Development –** According to the City of Fargo landfill officials, there are existing plans to invest and develop infrastructure to access more methane wells at the city landfill (P. Hanson, personal communication, March 12, 2016). Coupling these plans with the methane demands of CNS, $50,000 was assumed as existing development income for the project. A sensitivity analysis was not conducted for this variable.

**Ecosystem Services** – While not mentioned directly within either cost benefit analysis, it is important to note the potential and monetary value of the ecosystem services gained by investing in prairie vegetation. As mentioned previously in this chapter, prairie vegetation has the capacity to filter and recharge water supplies, provides habitat for wildlife and pollinators, and has a wealth of cultural benefits. Regardless of the difficulty scientists and researchers have of quantifying these services, it is clear there is a positive benefit of this investment. A sensitivity analysis in Table 2.17 and 2.18 illustrate the potential monetized benefits of these ecosystem services from $0 to $1,000/acre.

Table 2.17

*Ecosystem Services Sensitivity Analysis for Biochar Markets Scenario*

| **Ecosystem Services Value** | **$0** | **$250/acre** | **$500/acre** | **$1,000/acre** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $23,841,607 | $26,234,464 | $28,627,321 | $33,413,036 |
| **ROI for 10 Years** | 0.30 | 0.43 | 0.56 | 0.82 |
| **Break Even Point** | Year 8 | Year 7 | Year 7 | Year 6 |

Table 2.18

*Ecosystem Services Sensitivity Analysis for Municipal Use Scenario*

| **Services Value** | **$0** | **$250/acre** | **$500/acre** | **$1,000/acre** |
|---|---|---|---|---|
| **Total NVP Costs** | -$18,329,486 | -$18,329,486 | -$18,329,486 | -$18,329,486 |
| **Total NPV Income** | $9,690,179 | $12,083,036 | $14,475,893 | $19,261,607 |
| **ROI for 10 Years** | -0.47 | -0.34 | -0.21 | 0.05 |
| **Break Even Point** | > Year 10 | > Year 10 | Year 8 | Year 9 |

Finally, a sensitivity analysis was conducted for both scenarios to consider the impacts of the valuation of ecosystem services. It is currently understood monetizing ecosystem services is difficult to conduct, and can be a subjective process. The cost-benefit analysis did not include an initial assessment for these reasons, but it is important to try to depict the ecosystem services provided by this system. As featured in Tables 2.17 and 2.18, a range of monetary benefits from the ecosystem services were assumed ($0 to $1,000/acre). The total NPV costs remained constant for both scenarios at -$18,329,486.

For the Biochar Markets Scenario the total NPV income ranged from $23,841,607 to $33,413,036, and the ROI ranged from 0.30 to 0.82. The break-even point went from Year 8 to

Year 6 as the dollars per acre increased. The Municipal Use scenario exhibited a total NPV income range of $9,690,179 to $19,261,607, and a ROI range of -0.47 to 0.05. As the return per acre increased, the break-even point went from greater than Year 10 to Year 9. While it is clear the valuation of ecosystem services did not have as dramatic of an effect compared to the biochar prices or investment dollars, there was a greater impact on the Municipal Use scenario than the Biochar Markets scenario. More could be understood on how to effectively value ecosystem services at a local, regional, and global level.

## Economic Analysis Summary

This study conducted an economic analysis to explore the financial demands and outcomes of the CNS. A cost-benefit and sensitivity analysis were conducted for the two scenarios, Biochar Markets and Municipal Use. Overall, a return of investment can be realized with the Biochar Markets, but the Municipal Use scenario fails to break even before Year 10. Sensitivity analysis' were conducted to illustrate the variability within the cost benefit analysis.

Figure 2.3 depicts the total NPV revenues through a 10 Year period. This side-by-side analysis helps visualize the potential of each scenario. Within this timeframe the Biochar Markets scenario crosses the break even point at Year 8, while the Municipal Use Scenario will take well over Year 10 to break even. These scenarios do not account for federal or state seed money, or increased values in biochar or carbon credits. It can easily be inferred that with supplementary start-up funds, either system could see a change in profitability.

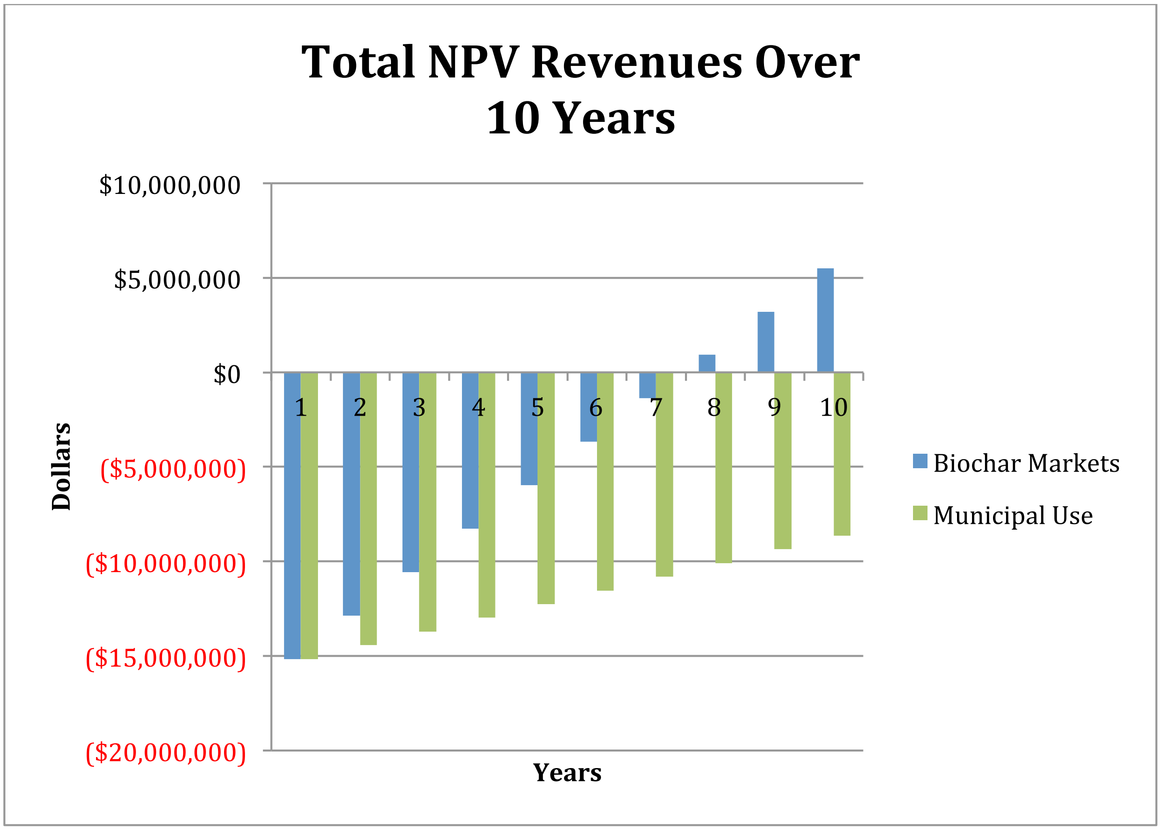

*Figure 2.3.* Total NPV Revenues Over 10 Years.

Overall, both scenarios provide a wealth of economic and financial information when assessing the viability of the CNS. While some parts of the system remain relatively constant, there are high variability components to be aware of. The commodity prices for biochar, facility cost and maintenance, and the carbon credit market can have a dramatic impact on the system. Similarly, the profitability of each scenario can be dramatically increased with additional start-up funds. Lastly, it is important to consider the financial benefit of the ecosystem services provided by natural systems. All in all, the CNS is fiscally viable option that demonstrates sustainable economic development. The next chapter will view the system through ripple mapping and a resilience framework.

# CHAPTER THREE

The previous chapters focused on describing processes and benefits of the CNS. This final chapter will synthesize these components through two areas of analysis. First, a ripple map will visualize the overall impacts of the CNS to the community of Fargo, North Dakota. Next, the system will be analyzed through the resiliency framework constructed by Simonson et al. (2015). Finally, the chapter will draw a conclusion and indicate areas of future research.

## Ripple Mapping

A tool often utilized in community development, ripple mapping can be useful in visualizing the intended and unintended consequences of community change. Developed by Kollock et al. (2012), ripple mapping pictures the impacts that resonate from an action, similar to how water ripples after an object is tossed into still water. When applied to community development, ripple mapping has helped communities gain consensus on issues that are difficult to conceptualize, and has initiated a "heightened sense of urgency," in thinking critically about the status quo (Kriesel, 2015).

Figure 3.1 indicates the ripple map that can be drawn from the CNS. This ripple map begins with the planting of prairie vegetation on the identified underutilized lands, and cascade towards promoting the quality of life of current and future generations. Two results can be seen after the prairie vegetation is planted: the biochar product and the resulting ecosystem services.

The biochar product results in four additional benefits: combustion, toxin absorption, land application, and water filtration benefits. These benefits can either be seen municipally or through entering the emerging biochar markets, all leading to an increase in community development revenues, and subsequently, improved community wellness. Community wellness can be seen through three characteristics in this system: physical health, mental health, and education. These characters are derived from the additional dollars for community development, as well as the increase in accessible prairie habitat.

Similarly, the ecosystem services provide three benefits: water filtration, habitat creation, and $CO_2$ sequestration. These benefits flow towards increased community development revenues, increased community wellness, and the capacity to mitigate climate change. Since the prairie vegetation effectively sequesters carbon emissions, this system can flow directly to the capacity to mitigate climate change, and subsequently flow towards investing in the community's future quality of life.

As most of the system flows towards improved community wellness, the benefits are seen to continue to flow towards the future quality of life of the community. Through ripple mapping, the benefits and outcomes of the CNS can be visualized. This study determined that though planting prairie vegetation, the community of Fargo, North Dakota can invest in the quality of life of current and future generations.

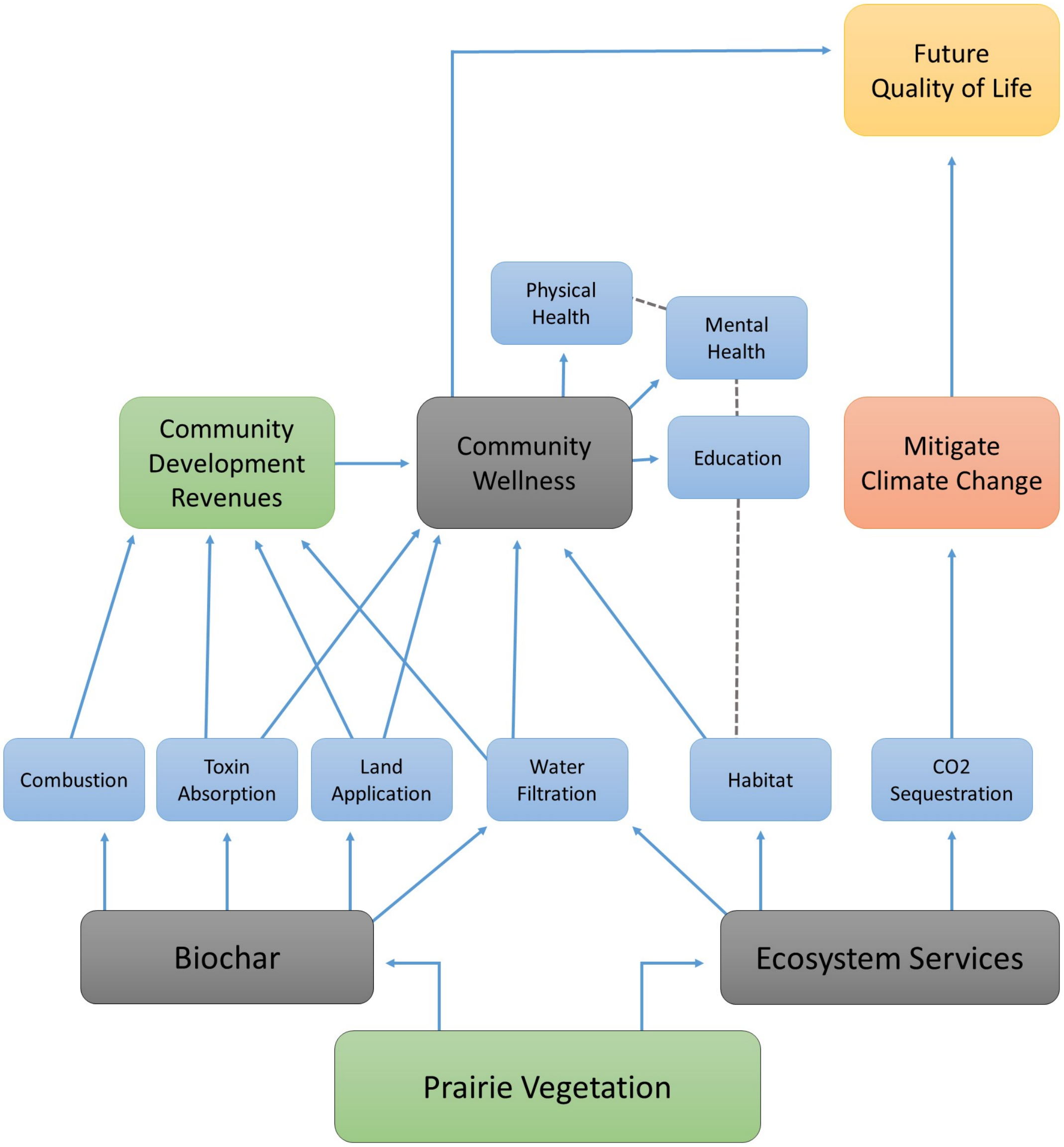

*Figure 3.1*. Ripple Map for Carbon Negative System

## Resilience

Similar to the concept of "sustainability," resilience is often a sought after ideal, but rarely clearly defined. In his research, White (2013) compares conceptualizing sustainability to the Roth vs. United States court decision on obscenity. Justice Potter Stewart wrote,

> I shall not today attempt further to define the kinds of material I understand to be embraced within that shorthand description; and perhaps I could never succeed in intelligibly doing so. But *I know it when I see it* (*Roth v United States*, 1964).

White concluded sustainability remains an ambiguous concept because it means different things for different people. Thankfully, resilience is no longer an ambiguous concept, to where we must rely on "I'll know it when I see it."

Recently, Biggs, Schluter, and Schoon (2015) constructed a framework to assist in conceptualizing resiliency. As depicted in Table 3.1, there are seven principles of resiliency. This framework suggests a resilient approach to sustainability "focuses on how to build capacity to deal with unexpected change." Additionally, the framework includes human influences within the analysis, instead of examining anthropocentric impacts external from the system. This framework will be utilized to synthesize the effects and benefits of this case-study.

Table 3.1
*Principles of Resilience*

| | |
|---|---|
| *Principle One* | Maintain diversity and redundancy |
| *Principle Two* | Manage connectivity |
| *Principle Three* | Manage slow variables and feedbacks |
| *Principle Four* | Foster complex adaptive systems thinking |
| *Principle Five* | Encourage learning |
| *Principle Six* | Broaden participation |
| *Principle Seven* | Promote polycentric governance |

Source: Biggs, Schulter & Schoon, 2015

### *Maintain Diversity and Redundancy*

The objective of the first principle is to promote diversity and redundancy on an ecological and a governing level. It is indicated systems with diverse and multiple components are less likely to be susceptible to a single unpredictable event. Rather, due to the diversity within the system, multiple parts may be able to provide a similar function, garnering "insurance" for unpredictable events. Similarly, if governance of the system is redundant in scope, as in multiple agencies are involved in the decision making or response process, their varying levels help provide the redundancy necessary to achieve sustainable socio-ecological processes.

When applied to the case-study, this principle can be illustrated with the ecological diversity of the prairie vegetation, and the stewardship of the governing bodies. As determined in Chapter Two, prairie vegetation provides a wealth of ecological services, including resilience to extreme weather events. In flood or drought scenarios, prairie vegetation naturally mitigates negative outcomes.

Additionally, redundancy in governance assists in achieving resiliency. The Dakota Audubon Society has actively managed and restored numerous acres of riparian area along the Red River to prairie vegetation, in the Urban Prairie Initiative (Marshal, 2015). Pairing Dakota Audubon's experience with other local stakeholders like the Longspur Prairie Initiative and governing officials like the Fargo City Council, proper stewardship can be derived from redundancy in the size and scope of these agencies. This is the result of a range of expertise' and organizational sizes coming together, approaching a singular issue. By focusing less on efficiently, and more on redundancy, resilient solutions to systemic problems will emerge.

### ***Manage Connectivity***

The second principle focuses on identifying and managing connectivity within the system. The authors acknowledge connectivity can be a good and bad concept for ecological systems. However, for the CNS, managing connectivity helps provide insight for existing and future ecological needs.

The first step in managing connectivity to obtain resilience is to map the area of concern. As identified in Figure 1.X in Chapter One, the identified underutilized lands for the system are fragmented across the Fargo community. This mapping helps illustrate the benefits and challenges affiliated with the system. Next, the important elements and interactions can be identified. For the CNS, a priority restoration area may be the corridor along the Red River, as this geographic area may provide the most biodiversity and ecological benefit. In contrast, the more isolated identified lands may need a different land management approach. By mapping and understanding where the system lies on the spectrum of connectivity, decision makers can conceptualize a clearer path towards achieving a resilient system.

### *Manage Slow Variables and Feedbacks*

The third principle focuses efforts on understanding the variables and outcomes of the system. Slow variables and feedbacks can be defined as processes and outcomes that are difficult to see day to day, but do provide a function or benefit over a longer period of time. The authors suggest monitoring and not interfering with these natural processes, promoting the inherent resiliency of the system.

Some slow variables and feedbacks within the CNS can be seen through the ecosystem services derived from the prairie vegetation. The carbon sequestration, increased biodiversity, maintenance of water quality, and increased aesthetic value can all be conceptualized and monitored over a longer period of time. By monitoring these variables, a better understanding can be achieved on how prairie vegetation naturally promotes resilience, in addition to what could be improved within the system. This information can then be relayed to decision makers, helping them make educated system management decisions.

### *Foster Complex Adaptive Systems Thinking*

The fourth principle to resilience focuses on developing complex adaptive systems thinking (CAS), which encourages stepping away from “reductionist thinking” and accepting that within a social-ecological systems, numerous variables are connected and interact at different levels. Additionally, CAS encourages accepting unpredictability and uncertainty. According to the authors, CAS thinking can be adapted through adopting a systems framework, anticipating uncertainty, adjusting social-ecological systems processes, and understanding the barriers of cognitive change.

Applying CAS thinking to the CN system, a systems framework can easily be adopted. Multiple figures (Figure 1.X, Figure 1.X, etc) within this study have provided example systems frameworks for the CN system. Decision makers can use these figures and diagrams to better anticipate uncertainty, planning for diverse scenarios. For example, what would happen to the CN system if a flood were to inundate the community? Or, what could be the impacts of drought conditions on the CN system? By adopting a systems perspective, it is easier to visualize and plan for uncertainties.

The management of the CN system may need to reflect the complexity of the natural system. The authors suggest adjusting the decision making process to reflect the complexity of the system, shifting form "traditional resource-by-resource" management to CAS thinking in decision making. Perhaps a coalition between City of Fargo officials and pertinent stakeholder organizations would be needed for the CN system to promote resiliency within and socio-ecological system. Finally, this principle highlights the important of acknowledging the limits of cogitative change. Just as it is difficult, and often uncomfortable, to prepare for future uncertainties, it is perhaps more difficult to deviate from normal operations. Decision makers ought to understand and accommodate for potential disruption and concern with transitions to CAS thinking. Once CAS thinking is adopted, the management systems will become as resilient as the systems' processes.

### *Encourage Learning*

This principle encourages continued learning and pursuit of understanding of the socio-ecological system. Through long-term monitoring of key social and ecological components, engaging the community, and by providing sufficient resources for the learning, long-term resilience can be achieved. They key understanding of this principle is to continue to learn from and improve the system once it is implemented.

After the CN system is applied to Fargo, North Dakota, community outreach and long-term monitoring can help promote this principle. As community members become more aware of the services and benefits of the system, more support and knowledge can be generated. Through this action, principle one is also achieved, as redundant stakeholders are informed and involved with the system at multiple levels. Additionally, long-term monitoring helps decisions makers make continually informed decisions, while encouraging adaptive management strategies. Finally, it is important resources are sufficiently allocated for this principle.

### ***Broaden Participation***

This principle focuses on providing the long-term infrastructure needed to build a broad base coalition that is engaged with the system. Through the initial efforts of principle five, principle six can be realized. The authors state this principle "helps build the trust and relationships needed to improve legitimacy of knowledge and authority during decision making processes." Ultimately, by providing sufficient financial, communication, and outreach protocol, a broad-based coalition can be maintained and engaged in the decision-making processes.

Since the CN system has the capacity to generate community development revenues, a small portion of these funds can be allocated to stakeholder outreach and communication protocol. These funds can be dedicated to communication training, outreach materials, and facilities needed to appropriately engage the public. Additionally, it will be important to provide avenues for community engagement and participation within the CN system. By providing areas of input and involvement, the broadened stakeholder participation can be maintained long-term, promoting socio-ecological resiliency.

### *Promote Polycentric Governance*

The final principle bridges many of the aforementioned concepts and principles. Polycentricity can be defined as a governance system in which multiple governing bodies interact to make and enforce rules within a specific policy arena or location. According to the authors, this is considered to be one of the best ways to achieve collective action when handling uncertainties or disturbances. By weaving together the broad coalition of engaged community members with the monitoring systems and adaptive management strategies constructed in the previous principles, polycentric can be achieved.

While this method of governance may not be the most efficient, by promoting redundancy within and outside of the system, the best solutions can be made through healthy discourse and discussion. For example, when applied to the CN system, decisions should be made by the City of Fargo, conservation organizations, local community members, and experts within the field. This principle promotes transparency and cooperation, two characteristics vital for socio-ecological resilience. If these seven principles are adhered to within the CN system, resilience can be achieved on a short and long-term scale.

## Conclusion & Areas of Future Research

Living within the Anthropocene is accompanied with a number of challenges, particularly mitigating anthropocentric carbon emissions. A potential solution of many be the CNS, a three-step process that focuses on planting prairie vegetation on underutilized public lands. This system has a variety of benefits, realized through ecosystem services, an economic analysis, ripple mapping, and as applied through a resilience framework.

If applied to Fargo, North Dakota, the CNS can effectively sequester carbon emissions while generating revenues for community development needs. When considering sustainability and resiliency, this system adequately fulfills the necessary principles in order for benefits to be realized in a short and long-term capacity. Ultimately, the CNS has the capacity to positively address contemporary climate change challenges through innovative thinking and resiliency.

Firstly, the CNS plants prairie vegetation on underutilized public lands that would otherwise be expensive and time consuming to maintain. Prairie vegetation has the capacity to effectively sequester carbon emissions, while providing additional ecosystem services. Next, some of the vegetation is harvested and processed at the City of Fargo's landfill. Here, the plant material is processed into biochar, which can be utilized in numerous ways, including as a soil amendment. The biochar can then be sold within the emerging biochar markets, assisting in generating new revenue streams for community development needs.

A carbon budget indicated the system is truly "carbon negative," as the prairie vegetation abates any carbon outputs within the system. The economic analysis illustrated the economic possibilities and financial constraints of the system. Through developing two scenarios, "Biochar Markets" and "Municipal Use", this study indicated it will be more profitable to enter into the emerging biochar markets, than to simply use the biochar municipally.

Finally, the CNS was illustrated through a ripple map and applied to a resilience framework. Through visualizing the impact CNS could have on Fargo, ND, it is clear the CNS can contribute to the local efforts in sustainable community development. By applying the CNS to a resilience framework, it is easy to visualize the next steps within the process, and the true resilience of the system. Overall, it is clear the CNS could have a positive effect on the community of Fargo ND, both ecologically and financially.

Due to the innovative nature of this study, there is much to be learned within this arena. This study's findings are limited to the scope of Fargo, North Dakota, so more could be understood on the regional and global effects of the CNS. More could be understood regarding the emerging biochar markets, in addition to how we can map and visualize sustainable community development. While thoughts and plans are emerging within the realm of sustainable community development, more could be known about the exact benefits of investing in systems similar to the CNS.

Furthermore, quantifying or framing the value of increasing the aesthetics of urban landscapes and ecosystem services of prairie vegetation could be more understood. Finally, there is a great need for more innovative and economically viable conservation practices. More needs to be understood on what can be done to effectively maintain the quality of life for current and future generations, within the contemporary challenges of climate change.

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