Measuring Carbon Dioxide Flux in Highway Buffer Zones

A Major Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute
In Partial Fulfillment of the requirements for the
Bachelor of Science Degree
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Abstract

Organic material and grasses have different potentials for carbon uptake. By redesigning roadway buffer zones with materials that have large carbon fluxes, a reduction of excess carbon in the atmosphere can occur. A Licor 8100-A mobile carbon dioxide testing unit was used to measure the carbon dioxide flux of various materials. Our results show that using a combination of different organic materials to create a carbon dioxide-absorbing buffer zone will take up a significant amount of carbon dioxide from the atmosphere. By implementing buffer zones that help reduce the amount of carbon dioxide in the atmosphere can potentially help in the efforts to combat global warming.

Professional Engineer Licensure

In the Civil and Environmental Engineering field, it is important for an engineer working in the field to have their Professional Engineering license. To attain a Professional Engineering (PE) license, engineers must first take the Fundamentals of Engineering Exam (FE). The FE test is administered by the state, and passing the test will certify the engineer as an Engineer in Training (EIT) in the state in which the test was taken.

In order to take the Professional Engineering test there are multiple tasks that must be done. The first is that an EIT must work under the guidance of a PE for at least five years. The EIT must also create a portfolio of their work to submit as an application to take the test. Last they must have a personal interview to make sure that they not only have the knowledge and understanding that is required to be a PE but also the right moral character.

Attaining the PE license is a great achievement but it also has significant responsibility. Professional Engineers have the ability to certify and stamp plans and blue prints. This certification states that the proposed build will not collapse, get destroyed or harm civilians. A PE has made a vow to the state that they will not put the lives of civilians in jeopardy.

Acknowledgements

Our team would like to thank our advisor, Professor John Bergendahl, for his continuous support and guidance. We would also like to thank Donald Pellegrino for assisting us in the use of the Licor 8100-A. Finally, we would like to thank the support of our friends and family.

Design Statement

This Major Qualifying Projects meets the Criteria for Civil and Environmental Engineering capstone design at Worcester Polytechnic Institute by incorporating economic, sustainability, ethical practices, and environmental concerns applicable to engineering practice. The team developed a list of criteria necessary to have the most effective buffer design. This was calculated and determined from the data our team acquired and our observations. We designed a buffer zone that included:

- Two-foot-wide, two-inch-thick layer of woodchip mulch
- 20 feet of grass, 4-6 inches in length
- Layer of trees and shrubs for noise buffer and added sequestration

This design buffer zone in the United States would increase the total flux by 19,292 mol/s. This is a major flux increase and this was calculated based on the data collected from the Licor Carbon Flux tester. Using our observations, we could make a realistic buffer zone design that could be implemented across the United States and be effective. In order to actually implement this plan, cost estimates were calculated for work and a dimensional setting. The approximation of 5 hours of work on a single 100-foot-long section of highway will cost around $1,613.50. This is a fairly accurate amount and easy to understand how expensive this project would be to implement seeing as there are hundreds of thousands of miles of highway buffer zones just in the Unites States alone. Our design incorporated all the aspects of engineering practice and implanted our skills to solve a real world-engineering problem.

Executive Summary

Carbon sequestration is a process where carbon dioxide is removed from the atmosphere and stored by plants and various organisms in soil. This process helps mitigate an increase in concentration of carbon dioxide in the earth's atmosphere. Different organic materials sequester carbon dioxide at different levels and rates. Utilizing these concepts, our team set out to determine landscaping opportunities to effectively sequester carbon dioxide and utilize approaches to create a buffer zone along highways that will provide for maximum carbon sequestration. Highway buffers account for almost half a million acres of land in the United States and based on the research conducted and data collected, a roadside buffer zone was designed that has the ability to create a large movement of carbon dioxide between the surface and atmosphere.

The first step of this project was to determine the most efficient surface material for sequestering carbon dioxide. Conducting field tests of various surface materials commonly found along roadways did this. This was challenging due to the fact that a large number of environmental factors contribute to the carbon cycle. Soil and material testing were conducted during the months of October and November, 2016. Locations for sampling were chosen to target potentially favorable surface material and eight surface materials were tested. The carbon dioxide flux measurements were taken using the Licor 8100-A mobile CO_2 flux-measuring instrument. The machine measured the amount of carbon dioxide that is transferring between the ground and the atmosphere, as well as between the surface itself. The data collected allowed for determination of direction and magnitude of flux, which was dependent on conditions, and provided basis for conclusions on the best surface material to sequester flux in the buffer zones.

From background research our team formed a hypothesis on how well different materials would affect carbon dioxide flux and sequester carbon. For example, it is expected that organic material such as grasses, trees, and shrubs would have a higher flux due to the ongoing photosynthesis and decomposition. The reference material in this project was pavement due to the fact that there were no organic materials present that would absorb or release carbon dioxide and should ultimately have a flux of 0. This material was used as a baseline comparison and confirmation that inorganic material was not suitable for consideration in our design to sequester CO_2 in a roadway buffer.

Our results showed that the locations with the greatest amount of carbon flux were the complex landscapes, including those including wood chips, grasses, plants, and trees. These results allowed us to design new concepts for buffer zones in order to improve overall CO_2 sequestration. We found that a two-foot-wide and two-inch-deep layer of woodchips bordering the highway would trap storm water runoff and sequester more carbon than gravel or other previous roadway buffers. After the woodchip mulch is a twenty-foot strip of seasonal grass grown between four and six inches in height would be appropriate. Grass of this height is ideal for carbon sequestration and maintaining a lively ecosystem of microorganisms that also contribute to carbon sequestration rates. Finally, the outermost strip of the buffer zone will be an assortment of planted trees and shrubs. This layer will provide both a noise buffer as well as another avenue for carbon sequestration. This design will likely have a greater overall impact on carbon dioxide flux and will increase the total carbon sequestration of riparian buffer zones.

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Chapter 1: Introduction

1.1 Global Warming

Global warming is a phenomenon first recognized in 1896 by a Swedish scientist named Svante Arrhenius. He claimed the burning of fossil fuels releases large masses of carbon dioxide in the atmosphere. He proposed a relationship between carbon dioxide levels in the atmosphere and increased global temperatures. Although his findings are accurate, they would not be verified until 1987 when scientific advancements conducted experiments helping prove his theory. One of these advancements was the development of infrared spectroscopy. This allowed scientists to collect data supporting the belief that carbon dioxide is warming the planet by absorbing radiation that would otherwise escape the atmosphere. It is expected that adding more carbon dioxide to the atmosphere would ultimately warm the planet to a greater extent. Originally, it was thought the ocean thought to be the adequate sink for all atmospheric carbon. However far less carbon dioxide is absorbed to the ocean waters than was originally thought. Oceans are very large and meant to absorb the carbon dioxide naturally produced in nature and part of the carbon cycle, however, the oceans do not provide enough if a sink for the carbon produced by human burning of fossil fuels.

The global annual mean temperature began to rise rapidly from 1980 onwards and the trends from1990 on can be seen in Figure 1, causing scientists to rethink their ice age theory in favor of global warming. Media coverage shifted quickly and allowed the theory of global warming to gain a much stronger following. The first major initiative taken to mitigate climate change was founded in 1988 after the greenhouse effect theory was accepted. The

Intergovernmental Panel on Climate Change (IPCC) and was founded by the UN Environmental Program and the World Meteorological Organization, collected and publicized this information Their goal was to predict the impacts of greenhouse effects resulting from human interference utilizing accepted climate models. The greenhouse effect was again in question in 1990 due to a lack of substantial evidence to say that the warming already experienced was anything out of the ordinary.

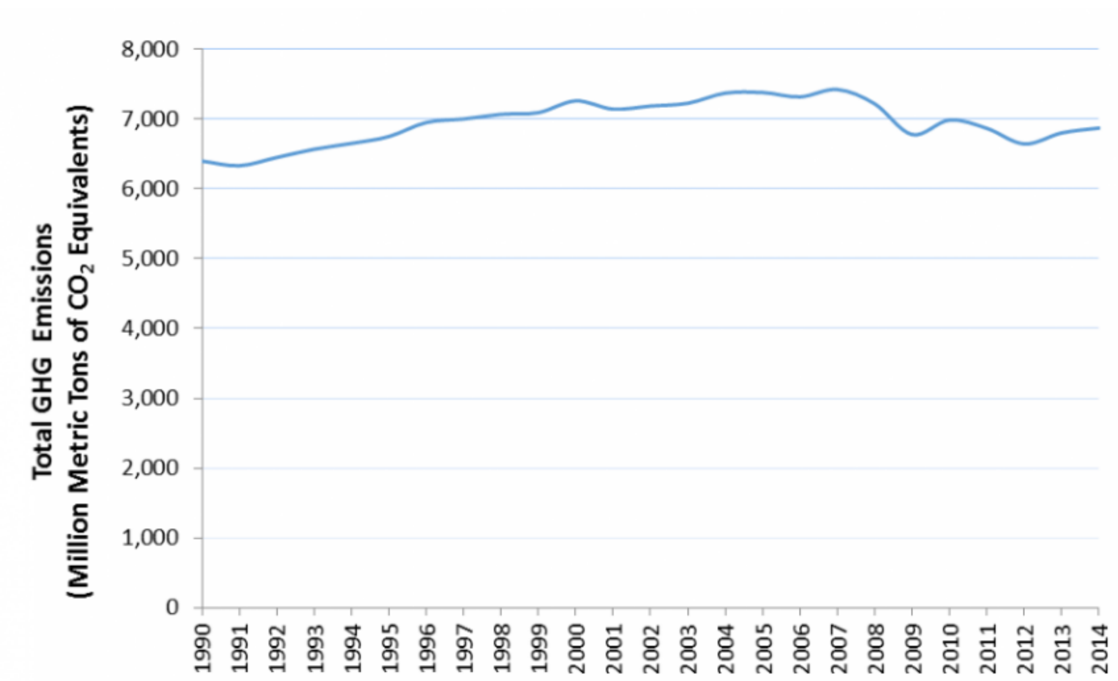

Figure 1: Total US Greenhouse Gas Emissions (NASA, 2016).

That quickly changed however, as the 10 hottest years ever recorded were between 1990 and 2003 as seen in Figure 1. As temperature keeps rising today, scientists are still looking for solutions to the problem. As research methods advanced it, was discovered that carbon dioxide was not the only greenhouse gas contributing to global warming. Methane and nitrous oxide were found to be large contributors and released from various sources. However, neither methane nor nitrous oxide were easy to measure or control, despite their significant impact. The characteristics of carbon dioxide put it at the forefront of research trying to mitigate climate change.

1.2 Causes

There are various forms of greenhouse gases and each has its own Global Warming Potential (GWP). The GWP of a certain species is a function of the amount of time greenhouse gas remains in the atmosphere and how much energy it absorbs (EPA, 2016). The higher the GWP, the more energy it will absorb and lower the GWP, the less energy it absorbs.

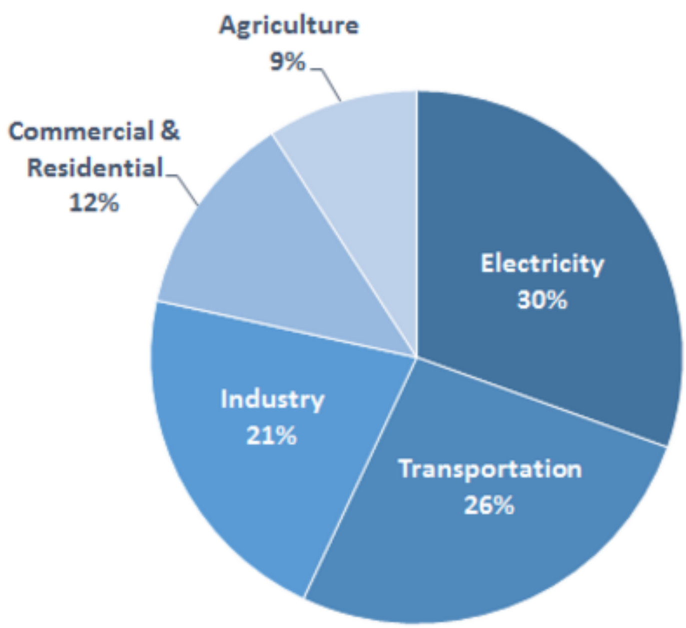

Figure 2: 2014 Greenhouse Gas Emissions by Source in the US (EPA, 2016).

Gases with higher GWP contribute more to the warming of the Earth (EPA, 2016). The two most significant greenhouse gasses are carbon dioxide and methane. Carbon dioxide is mainly created through the burning of fossil fuels, including coal, natural gas, and oil, as well as the burning of wooden products. It is also produced by internal combustion engines used in transportation as well as in combustion for heating homes and buildings. Methane is produced during transportation, decaying organic waste, fermentation, landfills, and natural gas and petroleum systems (EPA, 2016). The largest contributors of greenhouse gases are the transportation sector, where approximately 26% of carbon dioxide emissions are produced by the use of transportation in the US alone. Additionally, 30% of carbon emissions are from the production of electricity to power homes, industries, and businesses (EPA, 2014).

Depending on the gas, it can stay in the atmosphere for thousands of years (EPA, 2014). The continuous layer of gases creates a blanket-like effect where warmer air is trapped in the atmosphere. A smaller "blanket" is ideal because it allows heat to escape out of the atmosphere, while still keeping some air in the atmosphere, which is necessary for earth stabilization. However, a larger blanket will cause an increase in global temperatures, much like how a larger blanket warms you and keeps you warm.

1.3 Effects

During our lifetime, the effects of global warming are already appearing and causing a dramatic shift in the earth's climate. The results of global warming are significant and include a wide margin of affected animals, environments, temperatures/climates, and human health. This can be found in the loss of natural habitat among animals. Drastic examples include the melting of polar ice caps and the loss of coral reefs. Both of these occur due to rising water temperatures. Extreme temperature shifts and habitat destruction contribute to animal extinction. The animals are not able to adapt to their new environment fast enough and as a result, become extinct (Kleypas, 1999). Great extremes in temperature result in various weather extremes and the most common is a decrease in precipitation. Decrease in rain affects the production of crops, water shortages, habitat destruction, and climate change (EPA, 2014). Recently, there was a water shortage in California that has resulted in a declared a state of emergency in effect January 17, 2011 (DWR, 2016). With a shortage of water and an increase in very dry areas, wildfires are more likely to occur. Wildfires contribute to the increase of greenhouse gases in the atmosphere because of all the burning of organic materials as well as inorganic materials such as plastic found in homes and businesses (EPA, 2014).

Greenhouse gases lead to an increase in smog. Smog is a type of air pollutant derived from vehicular emissions and internal combustion engines (Healthline Editorial Team, 2016). Ozone is formed from oxygen by ultraviolet light and is present in low concentrations throughout the earth's atmosphere. Low-level ozone is the pollutant of concern and it is not made directly from car engines or industrial operations, but rather a reaction of ozone with sunlight and hydrocarbons to form the pollutants key to smog development. Smog leads to several human health problems such as: lung/throat irritation, coughing, increase in asthma, difficulty breathing, and a long-term effect can be lung damage (Healthline Editorial Team, 2016).

1.4 Reducing GHG's

A process called photosynthesis naturally removes carbon dioxide naturally. Photosynthesis removes carbon from the atmosphere and produces oxygen via plants and vegetation. This process, along with everything else that lives partakes in the carbon cycle in some form. Photosynthesis is the natural carbon dioxide remover. Theoretically, the planting of more trees and plants reduce the amount of carbon in the atmosphere. The more trees and plants, the more carbon dioxide can be removed via photosynthesis.

There are other ways humans can reduce their carbon footprint and reduce greenhouse gases. These can be simple as: turning off electronics when they are not plugged in and changing light bulbs to florescent light bulbs. These steps can reduce energy consumption by two-thirds as well as saving an average of $30 dollar per lifespan of the bulb.

The largest source of greenhouse gas emission is the burning of fuels due to transportation. Burning only one gallon of gas creates 20 pounds of carbon dioxide (Global Warming and Your Car, 2012). An average car holds approximately 14 gallons of gas; this means that over 280 pounds of carbon dioxide is produced when using one tank of gas. The simple ways one can conserve energy just by replacing light bulbs, turning off lights, taking public transportation and carpooling with friends can help lower one's own footprint on the earth and the production of greenhouse gases. However, it is not only the automobile that must be taken into consideration, every vehicle that requires fuel to move is contributing to the greenhouse gases in the atmosphere: motorcycles, trucks, buses, planes, boats, and trains all produce carbon dioxide into the atmosphere.

1.5 Carbon Dioxide Levels

Of all the greenhouse gasses, carbon dioxide is the most discussed and is arguably one of the most controllable. Carbon dioxide is released through human activities such as deforestation, burning fossil fuels, and other natural processes like respiration and volcanic eruptions. Since the dawn of the industrial era, atmospheric CO_2 levels have been rising at an alarming rate. The most recent atmospheric CO_2 measurement conducted by NASA was in August 2016. Their measurement showed that 404.07-ppm of CO_2 in the mid-tropospheric region. To put that into perspective, in August 2006 there was 382.10 ppm of CO_2. That's an increase of about 6% in a ten-year period (NASA, 2016).

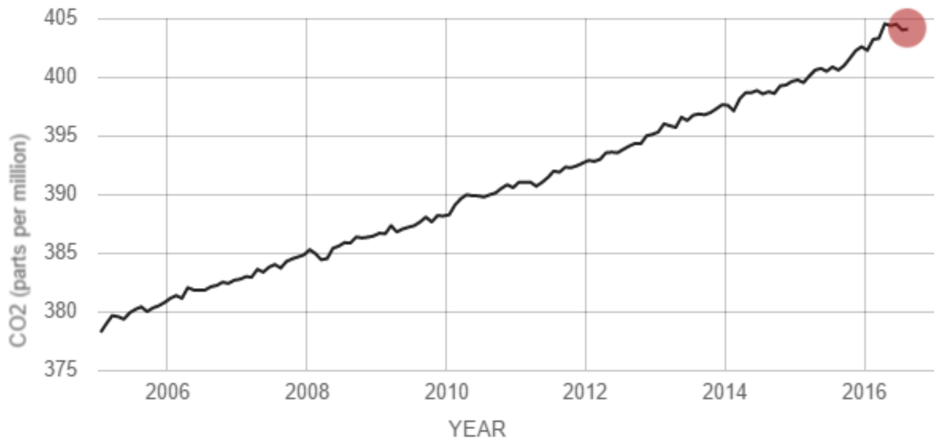

Figure 3: Carbon dioxide ppm Per Year from 2005-2017 (NASA, 2016)

As CO_2 levels have begun to rise, the effects can be seen across the world. Various equilibrium processes occur naturally, however the burning fossil fuels and production of more greenhouse gasses surpass the natural carbon dioxide sequesters. These equilibrium processes begin with the land and the water absorbing the carbon dioxide. Currently, land plants and the ocean absorb 55% of the additional carbon that people have put into the atmosphere. Roughly 30% of the carbon dioxide has directly diffused into the ocean through direct chemical exchange. Dissolving CO_2 into the ocean reacts to form carbonic acid, which is a weak acid. Thus, carbonic acid increases the acidity of water and since 1750 the pH of the ocean has changed by 30% (NASA, 2016). This acidification process is detrimental to marine life. Shellfish and other organisms such as coral reefs depend on a shell for survival and grow their shells by creating calcium carbonate. However, since carbonic acid reacts with carbonate, it forms a bicarbonate, which cannot be used for marine animals. This has caused shells to become significantly thinner and more fragile (Kleypas, 1999).

On land, plants flourish with the increase of carbon dioxide. It is estimated that approximately 25% of the carbon dioxide that is human-produced is absorbed by already existing plants due to use a process called photosynthesis (NOAA, 2016). Photosynthesis removes carbon dioxide from the atmosphere and turns it into glucose, a simple sugar used for food, and oxygen. Since there is more carbon dioxide in the air, this allows plants to grow more. The movement of CO_2 into the ground through plants can be defined as positive flux. Some plants have the ability to take in more carbon dioxide than others due to their size, location, and sequestering ability (NOAA, 2016). Typically, grasses and crops absorb less CO_2 than trees or shrubs. Although increased CO_2 levels are beneficial for plant growth, oxygen, nitrogen, and water are other important growth components (NOAA, 2016).

1.6 Legislation

Laws written by congress provide the authority for the Environmental Protection Agency (EPA) to write regulations. These regulations explain technical, operational, and legal details necessary to implement laws. The EPA helps regulated entities and operations meet federal requirements (Laws & Regulations, 2017). Some of the most important regulations include the Air Pollution Control Act of 1955, the Clean Air Act (CAA) of 1963, the two amendments to the Clean Air Act in 1977 and 1990, and the Clean Power Plan (CPP). These regulations played a crucial role in helping reduce GHG's and combat climate change. Although the CPP is currently on hold, if the court decides in favor for the CPP it will have drastic changes to the amount of emissions power plants will be able to output into the atmosphere.

The Air Pollution Control Act of 1955 was the "first federal legislative attempt to control air pollution at its source" (Laws & Regulations, 2017). The act diagnosed air pollution as a national problem and declared that research and additional action need to be taken. This act granted $25 million for 5 years of research by the Public Health Service. The main outcome of the act was that air pollution is an environmental hazard and it needs to be addressed. Public awareness is always the recommended first course of action needed to push for further laws and legislation in order to combat GHG's and climate change (Laws & Regulations, 2017).

The Clean Air Act was created in 1963 with the intention to "improve, strengthen, and accelerate programs for the prevention of abatement of air pollution (Evolution of Clean Air Act, 2016)". The Act granted $95 million over 3 years to state and local governments and air control agencies to research and develop air emission control programs. It also addressed the dangers of motor vehicle exhaust and pushed for the development of emission standards from the sources and stationary sources (Evolution of Clean Air Act, 2016). The '77 amendment was made primarily for the Prevention of Significant Deterioration (PSD) of the air quality in areas attaining the National Ambient Air Quality Standards (NOAA, 2016). While the '90 amendment greatly increased the federal government's authority and responsibility (Evolution of Clean Air Act, 2016).

On August 3, 2015, President Obama along with the EPA announced the Clean Power Plan. The objective of this plan is to reduce carbon pollution from power plants, while maintaining affordable energy and reliability (Hurley, 2016). This plan is the first national standard for carbon pollution from power plants. On February 9, 2016, the U.S Supreme Court put a hold on the CPP. Twenty-seven states, multiple companies, and businesses requested a block of the CPP. The court voted 5-4 in favor of putting the CPP on hold while the court continues to discuss and battle over the legality of the CPP. If the CPP is implemented, it will have a large impact on companies forcing them to cut air pollutants outputted into the atmosphere and will greatly reduce GHG's (Hurley, 2016). All these regulations created an increased public awareness of air pollution hazards as well as helped reduce GHG's and in the process to combat global warming.

1.7 Major Findings

Carbon sequestration is the process of removing carbon dioxide from the atmosphere and holding it in another state such as solid or liquid in another location other than the atmosphere (Interior Releases, 2012). The carbon that is absorbed or "sequestered" by natural means reduces the amount of CO_2 in the air. Studies show that natural carbon storage is found in forests, grasslands, and wetlands. In the western U.S., forests and vegetation sequester 100 million tons of carbon each year. This accounts for approximately 5 percent of the nation's estimated carbon dioxide emissions. Confirming the role of vegetation in carbon sequestration can help lead to a solution the nation's increased carbon emissions. This information led us to believe that the ultimate solution is to create a buffer zone filled with trees, however it is not a realistic solution by any means due to factors of driving safety alone. Carbon dioxide levels change over the course of a year and fluctuate with the seasons. Plants take up more carbon dioxide in spring and summer when they are growing and release it as they die in fall and winter (Seasonal fluctuations, 2016). The emission of carbon dioxide from the burning of fossil fuels increases the range of CO_2 fluctuations. However, with the increases in temperature due to global warming, more bushes, shrubs, and trees are growing to a greater extent, leading to a greater carbon sequestration (Seasonal fluctuations 2016). This shows that there is a correlation between climate and vegetation. The type of vegetation also affects the CO_2 flux. Some plants are better at absorbing CO_2 and others are more efficient at converting CO_2 to oxygen. Learning about these types of plants is critical in helping find the best solution to create a greater CO_2 flux.

Chapter 2: Background

2.1 Carbon Sequestration

The focus of this project was to examine the effects of various natural ground surfaces on the carbon cycle, in particular consideration to carbon flux into landscaping and respiration adjacent to roadways. The carbon cycle is defined as a series of processes by which carbon compounds are interconverted in the environment (Bruce, 1999). All living things are made of carbon, it is in the ocean, air, and even rocks. While carbon is in the atmosphere, carbon is attached to oxygen creating the gas carbon dioxide (Schwartz, 2014). Vegetation absorbs carbon dioxide and creates oxygen and their own food by the process of photosynthesis.

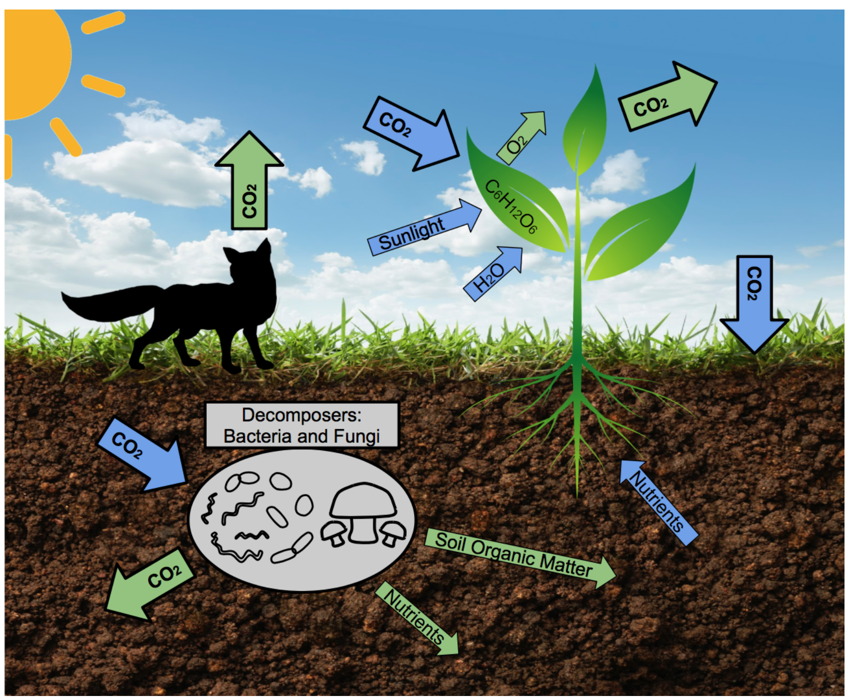

Figure 4: Image Depicting the Carbon Cycle and Carbon Sequestration.

When vegetation dies, the carbon stored in the plant is buried and turns into fossil fuels such as coal and oil over the course of millions of years (Lai, 2004). Carbon dioxide is a greenhouse gas and is what traps heat in the atmosphere. CO_2 is essential for life, however with the continual burning of fossil fuels and releasing the stored carbon in the earth back into the atmosphere, there is a 30% increase of CO_2in the atmosphere than 150 years ago (Bruce, 1999).

Carbon dioxide flux is the rate of exchange of carbon dioxide between the soil and air for a specific area and time. The units used in this project were: µmol/m^2/s. Natural carbon sequestration is the process in which biological and biochemical mechanisms remove carbon dioxide from the atmosphere and hold it in a solid or liquid form (EPA, 2016). The ocean absorbs about half of the current total emissions produced today and can be seen in Figure 4. This is because soil stores carbon in the form of organic matter twice as much as the atmosphere (EPA, 2016).

Carbon dioxide diffuses into the soil naturally. However, the vegetation associated with CO_2 originating from the biochemical process of photosynthesis does not represent the full amount of CO_2 that is held in the soil and vegetation matrix. Inevitably respiration occurs, releasing CO_2 back into the atmosphere constantly. However, plant respiration levels are diurnal; they peak at night and are at a minimum at noon (EPA, 2016). During the day plants produce ten times as much oxygen through photosynthesis than they use at night, which is their peak respiration time (Lai, R, 2004). It is hypothesized that temperature and moisture affect CO_2 respiration. Verifying this theory, a study in Montana that shows a CO_2 flux peak in a dry summer. In general, a high moisture content tends to have more stabilized respiration than drier soils (Lai, R, 2004).

Carbon sequestration is great way to reduce greenhouse gas emissions concentrations in the atmosphere (MIT, 2016). It takes into account two other efficient ways of reducing carbon: improving energy efficiency and increasing the use of non-carbon energy sources. Increasing interest in carbon sequestration is also due to the fact that carbon sequestration is very compatible with large energy production (MIT, 2016). The burning of fossil fuels, which releases carbon trapped below the earth's surface, converts this solid and liquid carbon to gaseous carbon dioxide. There are many ways to sequester carbon and one of them involving trees is called terrestrial sequestration. Studies have identified trees as one of the most effective means of sequestering carbon. Qualities to look for in trees are: fast growing and long living trees. As well as trees with large leaves and requiring minimal maintenance (Tribal Energy, 2016).

2.2 Surface Material

In recent years, the surge of research directed to understanding the carbon cycle and quantifying the sources, sinks, and transport processes that constitute the cycle (Lai, R, 2004). In 1998, the Soil and Water Conservation Society conducted a workshop on carbon sequestration in soils. The primary goal of the workshop included finding a definitive means to explain carbon sequestration to mitigate greenhouse gases. The workshop also aimed to gage the potential for soil carbon sequestration, the measures necessary to reach this potential, and the available methods for measuring carbon sequestration. One of the main focal points from the workshop included the idea that different topographical features have their own level of carbon sequestration ability. This is due to many factors mostly consisting of large sink pools, which is the location for sequestered carbon (Lai, R, 2004).

There are five main global carbon pools: the largest pool is oceanic, followed by geologic, pedologic, biotic, and atmospheric. These pools are all interconnected and carbon circulates throughout them all. The pedologic, or soil pool consists of soil organic carbon (SOC) and soil inorganic carbon (SIC), which is important to drier soils. SOC concentrations range depending on the location of the soils. Soils located in arid regions typically have low concentrations of carbon and soils in temperate regions tend to have higher concentrations of carbon (Lai, R, 2004). The highest concentration is in organic and peat soils. Carbon pools are also beneficial to humans because the functions of sink pools provide value to human wellbeing.

		Soil organic carbon		Soil inorganic carbon	
Soil order	Area (Mha)	Density (tons/ha)	Pool (billion tons)	Density (tons/ha)	Pool (billion tons)
Alfisols	1262	125	158	34	43
Andisols	91	220	20	0	0
Aridisols	1570	38	59	290	456
Entisols	2114	42	90	124	263
Gelisols	1126	281	316	6	7
Histosols	153	1170	179	0	0
Inceptisols	1286	148	190	26	34
Mollisols	901	134	121	96	116
Oxisols	981	128	126	0	0
Rocky land	1308	17	22	0	0
Shifting sand	532	4	2	9	5
Spodosols	335	191	64	0	0
Ultisols	1105	124	137	0	0
Vertisols	316	133	42	50	21
Total	13,083		1526		945

Figure 5: Soil Carbon Pools of World Soils (Garrard County, 2012).

Some of the functions of SOC pools include: a source of plant nutrients, absorbance of water at low moisture potentials, a source of strength for soil aggregates leading to a reduction in erosion and providing a buffer against possible soil fluctuations, such as the intrusion of pesticides (Lai, R, 2004).

There are three main factors that determine the amount of carbon sequestered in soil. These are: the rate of input, the decomposability of the organic matter and the depth in the soil that the carbon is stored (Lai, R, 2004). Carbon from plants enters the soil organic matter in the form of root material. In different regions, herbivores ingest plant material and carbon enters the

SOC via excretion. Within the soil, the plant fragments reduce to light-size fractions and the leachates and exudates from the plants combine with fungi and earthworms to essentially encase light fractions in the soil. Soil Microaggregates and macroaggregates forms around these light fractions through chemical binding of carbon to soil mineral particles. This forms organic carbon and a large portion of this carbon is returned to the atmosphere by respiration from roots (Lai, R, 2004).

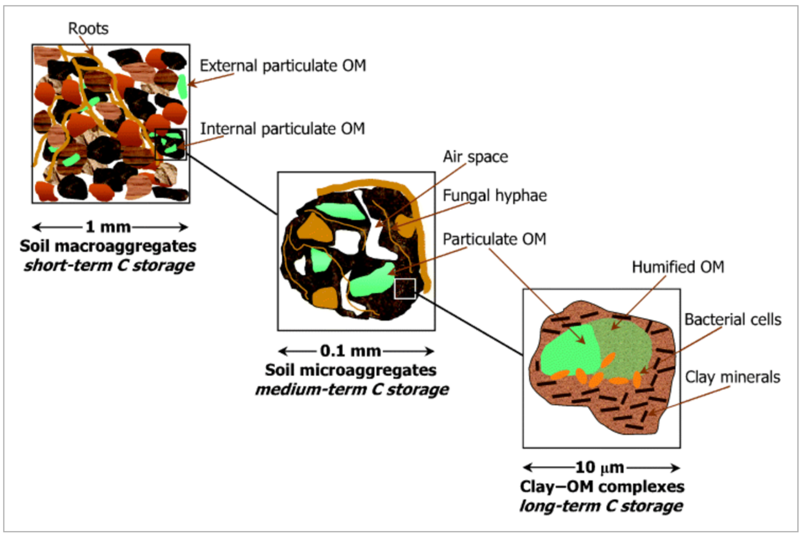

Figure 6: Image of soil Macro and Microaggregates in soil (Lai, R, 2004).

Substantial stocks of carbon in temperate grasslands are located below the ground in the roots and soil. It is estimated that around 20% of the world's carbon stock is held in grasslands (Schwartz, 2014). The organic carbon that forms is stored in carbon pools and the carbon is then measured from these pools. The roots, leaves and stems from which the soil organic matter is composed of breakdown simultaneously and at different rates depending on the species and climate conditions. Plant roots not only contribute to soil carbon when they die and decompose, but from microbial activity in the rhizodeposition produce similar products to normal root exudation. Roots and mycorrhiza, a type of fungus that grows either inside the plant or on the surface of the roots (Gold, 2011), are the main mechanisms for transporting carbon into the soil. A plant with mycorrhizae may have on average 15% more carbon to soil transfers than plants without any mycorrhizae. Hyphae are thread like filaments that are on most common mycorrhizal fungi and increase the reach of a plant's access to nutrients and water. What makes hyphae effective is the substance glomalin that is crucial in the soil structure and carbon storage (Schwartz, 2014).

2.3 Soil Carbon Storage

Organic matter is a key component of soil that affects its physical, chemical, and biological properties (Ontl, 2012). Benefits of soil organic matter (SOM) include the improvement of soil quality through increased retention of water and nutrients, which result in greater productivity in plants. SOM improves soil structure and reduces erosion. This leads to improved water quality in groundwater and surface waters. Better water quality means increase in food security and decreased negative impacts on ecosystems (Ontl, 2012). Since the beginning of recorded history, societies have understood that human activities contribute to soil productivity depletion and the ability to produce food and release stored carbon into the atmosphere. For example, the destruction of the rainforests that hold significant amounts of stored carbon stored in terrestrial ecosystems contribute to the CO_2 in the atmosphere when the trees are uprooted and cut down (Ontl, 2012).

Soil organic matter is composed of soil microbes including bacteria and fungi, decaying material from once living organisms, and fecal matter. SOM is a heterogeneous mixture of a range of plant life from fresh plant residues to highly decomposable matter known as humus. The organic compounds that form SOM are enriched with carbon. The amount of carbon in the SOM is called the soil organic carbon (SOC) levels. SOC levels result from the interaction of several ecosystem functions such as photosynthesis, respiration, and decomposition.

2.4 Biochemistry and Biological Contributors

Vegetation is the greatest mechanism available to achieve carbon sequestration. The natural biological processes of plants involve the uptake of carbon to use as a reactant in their biochemical processes (Gold, 2011). This makes the buffer zones on the sides of highways an intriguing option in combating the release of greenhouse gases from automobiles. However, there are many other aspects of buffer zones that produce their own atmospheric carbon. The various other biological species that inhabit buffer zones generate large amounts of atmospheric carbon through naturally occurring biological and chemical processes. The relationship between the carbon creators and carbon sequestering plant life is impacted by many environmental changes, and understanding how this relationship changes is crucial in optimizing carbon sequestration.

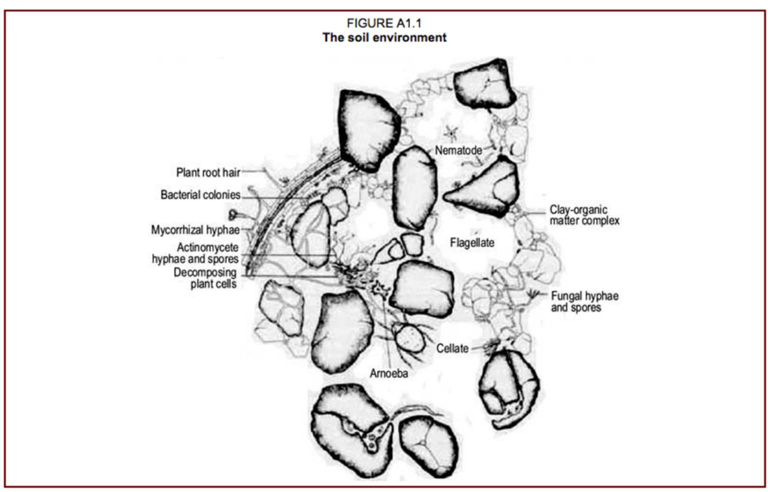

Figure 7: Microscopic Image of the Composition of Soil (Gold, 2011).

Biological contributors are naturally found organisms and biological material that comprise a living structure. Different biological aspects found in the ground, living, or nonliving, produce large amounts of CO_2. The type and quantity of the biological matter can change depending on the region (Gold, 2011).

2.4.1 Microorganisms

Microorganisms comprise the largest percentage of biological matter in buffer zones. A microorganism is a microscopic living organism that includes bacteria, archaea, and most protozoa (Schwartz, 2014). Due to the variety of individual species, it is difficult to segregate and identify the different microorganisms. The overall carbon contributions are generalized and combined, making them the largest contributors of carbon amongst the biological matter, which can be seen in Figure 7. Adding certain beneficial microbes, such as bacteria, will help stimulate soil cycles (Schwartz, 2014). The main method of carbon production is through the microorganism's natural respiratory processes. As the microorganisms consume oxygen and digest food for nutrients, they produce carbon dioxide as a byproduct. Depending on the concentration of microorganisms, this process alone can generate a greater amount of CO_2 than the burning of fossil fuels (about 10:1 ratio Pg C/yr) (Raich, 1992).

Aside from respiration, microorganisms also generate significant amounts of greenhouse gas when they die (Hoogmoed, 2016). As the decomposition process begins, the breaking down of chemicals within the organisms releases large amounts of nitrogen, methane, and CO_2 as the dead organisms decompose further through mineralization, they produce more carbon that is released into the atmosphere (Hoogmoed, 2016).

The rates at which these microorganisms release carbon into the atmosphere are not constant. Moisture and temperature levels impact the natural processes of these microorganisms quite drastically, however not all the time. These variables impact the effectiveness of respiration and an increased fatality rate of microorganism colonies.

2.4.2 Organic Detritus

Organic detritus includes a wide variety of dead biological material that through decomposition provides sustenance to microorganisms and generates atmospheric carbon dioxide. Communities of microorganisms, which decompose the biological material, normally colonize detritus. There are many different types of organic detritus ranging from dead tree roots underground to larger animal carcasses above ground. While these materials may fail to create their own significant source of CO_2 they provide materials for decomposers and scavengers to carry out their own carbon producing processes.

2.5 Plant Life

Vegetation in buffer zones is primarily used to sequester carbon dioxide and control CO_2 flux. Grass and trees are the greatest source of this flux and sequestration because carbon dioxide is essential for the process photosynthesis. Photosynthesis breaks down the CO_2 and converts it into sources of energy for the plants, such as glucose that is the plant's food supply, as well as oxygen which is released back into the atmosphere (Kampichler, 1998). The chemical components of photosynthesis are shown in equation 1.

$$CO_2 + H_2O \rightarrow C_6H_{12}O_6 + O_2 \qquad \text{(Equation 1)}$$

Large concentrations of plant life provide sufficient carbon sequestration, but as the microbial colonies in buffer zones grow and become more diverse, the task of sequestration becomes more difficult. The result is a positive CO_2 flux, where more carbon is released than can be absorbed by the plants. The density and diversity of vegetation in buffer zones impacts the overall CO_2 flux of an area (Kampichler, 1998). Dense vegetation sequesters more carbon, however, it is a more sustainable habitat for microbes to flourish in. The direct impact of this varies greatly depending on the species of flora and fauna present. It is important to consider the impact of vegetation when assessing the factors of CO_2 flux.

2.6 Seasonal Impacts

For regions that experience drastic changes from season to season, carbon flux tends to vary in accordance with the changing environmental conditions. Factors impacting the overall CO_2 flux include: changes in air and soil temperatures, moisture levels, the length of each day, and freezing.

2.6.1 Summer

In the warmest months of the year, soil temperatures rise and overall precipitation decreases. It is expected that these conditions increase aboveground respiration, however, the CO_2 level decreases because plants absorb more carbon dioxide (Davidson, 2006). This concept of CO_2 moving into the ground through plants is defined as positive flux. Longer days encourage photosynthesis to occur in both flora and fauna, which take up more CO_2 as a result. While drought is another factor to consider, many plants have access to deep soil levels, allowing them to collect water even when a lack of precipitation may dry out the upper layers of soil (Davidson, 2006).

2.6.2 Winter

A study conducted regarding seasonal patterns of soil respiration revealed that soil respiration is highest in the winter than every other season. It is noted that the increased respiration levels are due to two major factors: temperature and moisture (Davidson, 2006). New England winters often drop below 32°F, causing water in plants and in the ground to freeze. In order for plants to avoid freezing, plants create “antifreeze” proteins. These proteins are secreted into the cell walls and prevent ice crystals from forming inside the cell. Additionally, some plants are dormant during the winter and rely on glucose reserves in order to survive.

In Japan, Shigeru Mariko that focused on CO2 flux from soil and snow surfaces conducted a two-year experiment. The study found that there was little to no diurnal variation of CO_2 flux during the winter when snow is covering the ground. This is to be expected because plants create the diurnal CO2 flux variation. However, the reason why the surface is still creating a constant flux is due to the fact that the soil temperatures are still satisfactory for microbial organism and plant root respiration (Mariko, 2000). If soil temperatures drop too low, microorganisms can die and release carbon dioxide into the atmosphere (Hoogmoed, 2016). Although there is a constant rate of CO_2 flux, the study showed that there is significant decrease in CO_2 flux during the winter months. Winter showed a general CO_2 flux of less than 0.5 g C m^2 d^{-1} whereas spring months, such as May, had a CO_2 flux of roughly 2.0 g C m^2 d^{-1} (Mariko, 2000).

2.6.3 Spring

During the spring months the increase in water availability allow plants to photosynthesize more frequently. As a result of the rise in photosynthesis by plants seasonal CO_2 fluctuations occur. During the warming months of spring more CO_2 is absorbed, whereas in the cooling months of autumn/fall plants conserve energy by decreasing photosynthesis and increase respiration (Monroe, 2013). CO_2 plays an important role in soil organic matter (SOM) by helping the soil maintain its water retention capacity. During the warming months of spring it is crucial for the water retention to be at its capacity for the hotter and drier months of the summer for photosynthesis to continue (Schwartz, 2014).

2.6.4 Autumn

Originally, a rise in temperatures have been a positive outcome for growing seasons as they tend to become longer resulting in an increase in photosynthesis. Scientists believe that warming of spring and autumn increases carbon sequestration and the overall carbon uptake rises (Dumé, 2008). However, this is not true; Shilong Piao and his colleagues used atmospheric trends from the last twenty years to determine trends in earlier autumn-to-winter carbon dioxide build up. This means that there is actually a shorter net carbon uptake period and a decrease in carbon sequestration in autumn due to the ecosystems respiring. Although plant respiration and photosynthesis increases as the autumn seasons warm, respiration surpasses photosynthesis leads to a net loss of carbon dioxide. "The findings also suggest that if future [autumn] warming occurs at a faster rate than in spring, the overall ability of the northern ecosystems to sequester carbon may diminish (Dumé, 2008)". Since CO_2 in the atmosphere decreases in growing seasons due to the rise in photosynthesis, and increases during the rest of the year from respiration, then if respiration surpasses the photosynthesis in the growing seasons then there will be a decrease in the total amount of CO_2 being sequestered.

2.7 Roads

In 2006, it was reported that approximately 250 million cars and trucks are on the roads in the United States (McNichol, 2006). In 1956, The Federal-Aid Highway Act called for the construction of 41,000 miles of highways to be built. The idea of how this would affect the environment and the amount of CO_2 produced from automobiles was not a primary concern. However, by examining the factors of road construction, such as the materials and buffer zones can give us a better understanding of the amount of carbon in the ground that is in the proximity of a road.

Highway construction begins with planning and design. The planning of the highway begins with collecting data about roads such as: road and bridge conditions, traffic volumes, and vehicle crashing statistics. Using this data, engineers, transportation planners, environmentalists, and landscape architects identify the trends needed to construct a highway. Money to fund roads is paid for by gas taxes. Depending on the state, the federal tax for a gallon of gas is 18.4 cents (as of 2006). The next step is design, the factors that affect highway designs are: location, soil properties, drainage, traffic volume, future development, and the effect on the environment (McNichol, 2006).

After the designs are made, then the earthwork can begin. Earthwork is one of the most important factors in highway construction because it establishes a stable foundation. The contractor first builds embankments, then uses a bulldozer to level the dirt. Leveling the bumps and filling in the dips will help stabilize the road for years to come. The dirt is sprayed with water and compacted, while this is happening, drains, and sewers are installed. The center of the highway is elevated slightly so water can run off the road. After rigorous inspection, the road is ready to be paved (McNichol, 2006).

The two main highway pavement materials used are asphalt and concrete. Asphalt uses bitumen, a mixture of hydrocarbons that occur naturally or man-made from coal or petroleum. The bitumen is used to provide adhesion bonding sand and crushed rock. This mixture is heated to 300 degrees Celsius and is spread and compacted on the roadbed. Concrete uses cement and water to bind aggregate. The concrete is placed into molds called forms where they are trimmed and joints are cut in, to allow the concrete slabs to expand and contract with the temperature changes. After pavement is complete, different tests are performed for quality and drainage. The final steps are creating permanent markings for the road lines and planning the surrounding landscapes including creating buffer zones next to roads (McNichol, 2006).

2.8 Buffer Zones

Buffer zones are undeveloped, open spaces that border a highway. The primary use of buffer zones is for noise control of heavy traffic (McNichol, 2006). Usually noise barriers are solid objects constructed to prevent highway noise. Vegetation is very common for highway sound reduction. Mostly trees and tall shrubbery is used for this and in order to be effective, the vegetation must be high, wide and dense enough to block out the noise as seen in Figure 8. Buffers with vegetation also help reduce concentrations of pollutants from vehicles.

Figure 8: Image Depicting a Standard Noise Barrier Buffer (McNichol, 2006).

Many different types of materials can be used on the side of roads, also called right-of-ways (ROW). Some of the more common materials that can be found on ROW's are dirt, grass, sand, and rocks. With very few information given about the materials used on ROW's we are assuming that materials aren't selected to be put on the ROW's. Instead materials that are already found when constructing a highway are used. In New England, most of the materials found are dirt or grass.

2.9 Past Projects

Past projects are an immense source of information and assessing the steps taken in conducting a carbon sequestration project. The current research found provides key examples of an organization performing a carbon sequestration project. The New Mexico Department of Transportation (NMDOT) Carbon Sequestration Pilot Program (CSPP) designs quantify the sequestering ability of carbon in the grasslands next to highways. This project provides helpful information and insight on how to best design and test a media for its carbon sequestration properties.

In 2008, New Mexico's Department of Transportation (DOT) joined the carbon sequestration pilot program. This program is a four-year research project attempted to quantify the amount of carbon the grasslands can sequester along the highways right-of-way (ROW). Its aim is to help a state's DOT reduce emissions and maintenance costs, as well as cultivated a new beneficial environmental service. The project explores the feasibility of reducing and sequestering greenhouse gas emissions through the use of vegetation along the highway and the ROW. This project sets a reference point including recommendations and considerations for future projects to look back on. The CSPP is one of the first of its kind, so the results from the project will determine if other similar projects and programs efficient on a larger scale.

Establishing four key expectations before the project begins, allows for an attainable goal. The first expectation was to determine the amount of available acreage for carbon sequestration. Second, was to estimate vegetation cost for revised planting techniques. Third, was to estimate the carbon credits using the enhanced management techniques. The fourth was to identify a parameter that was able to confirm the amount of carbon sequestrated. These four expectations greatly influenced and guided the steps taken in determining the results. The information that was available was only in certain files, making it extremely time consuming to gain all the information needed. Considering this challenge, the NMDOT decided that when the collected information was obtained it would be directly tied to the estimations of sequestered carbon and also revenue generated.

Since completing the project, NMDOT learned many lessons in constructing a carbon sequestration project. Some key points to take away from the project are: to identify and contact those who are knowledgeable of carbon sequestration and carbon credits, analyze the maintenance of the ROWs, and understand that carbon sequestration won’t be the top priority of a state’s DOT.

Chapter 3: Methodology

The following experiments were conducted in accordance with the described objectives, in order to measure the various factors in regard to soil CO_2 flux. After researching CO_2 flux, the factors found that impact the flux included: temperature, season, time, weather, precipitation, and concentration of organic material in soil. In order to streamline the tests, we set the testing parameter, while simultaneously expressing others to see possible trends and verify the hypotheses. Each field test also used the same LICOR parameters (Observation Length, Dead Band, Observation Count, and Pre and Post –purge). Additionally, each soil collar was installed in a similar fashion. All of our tests were conducted within the same two-hour window of time, 3:00 PM to 5:00 PM, which would eliminate any diurnal flux that was occurring. By keeping all of these factors constant, this allows us to compare each field test to another. With time and testing parameters constant, it allowed us to see trends involving temperature, precipitation, and ground cover/soil type.

Although the LICOR testing device allows us to have a wide spread of data pertaining to each field test, certain parameters could not be controlled. Although temperature and soil moisture content are both recorded with numerical values, they are uncontrollable parameters. Ideally, each field test would be taken at the same temperature and soil moisture content, thus leaving the only other dependent variable as the soil type and the type of ground cover. Unfortunately, since the weather was constantly changing over the course of the month of November, we were tasked with trying to understand what temperature and moisture content was doing to the soil, and look past it to see the overall trends to find the ideal ground cover for sequestering the greatest amount of CO_2.

3.1 Installing the Soil Collar:

1. Locate appropriate place to run experiment.
2. Place a Soil Collar on the ground
3. Use a rubber mallet to tap the Soil Collar down so that roughly 2 cm is showing above the ground so that the collar can be adequately installed. If the ground is too hard a trowel or knife can be used to create a channel in the ground so that the Soil Collar can be more easily installed.
4. Check to see that the Soil Collar is secure and does not move if touched.
5. Measure the height of the Soil Collar from the ground (this will be used for the chamber offset).

3.2 Field Test:

1. Install a Soil Collar a few hours to a day prior to running a test.
2. Turn on the LICOR LI-8100A by pressing the power button. Simultaneously, turn on the computer and open the LI-8100A 4.0.0 Software.
3. Connect the LI8100A to the computer via a serial to USB adapter. Once the device is connected to the computer press the connect button in the top left corner of the software browser. Then select the port that the device is plugged into.
4. Place the chamber over the collar and set the soil temperature and soil moisture probes at the desired depths and distances from the chamber.
5. Once the device is fully connected wait until the IRGA category says “READY” in the Status section of the window.
6. Press the “Setup” button on the top of the window and click “Chamber Measurement” from the drop down menu. Or press the CO_2 icon.

7. This will prompt you with a new window. Click the second tab titled “Observation”. In this section of the window you can change different aspects of the test: Observation Length, Dead Band, Pre and Post Purge, and Observation Count. Change the settings around to fit the individual testing needs.
8. Title the test and press the “Start Measurement” button in the bottom left corner.

Chapter 4: Results

The goal of this project was to test various ground surface materials to determine the greatest carbon flux. Movement of any material from one place to another is called a flux and carbon flux is the transfer of carbon from one pool to another. Fluxes are typically expressed as a rate per surface area. The rate units are in terms of amount of substance displacement over a period of time. In this experiment, flux units were ($\mu mols/m^2/s$). We were looking for a material that would best take-up carbon from the atmosphere. A single pool of carbon can often have several fluxes both adding and removing carbon simultaneously. The size of various fluxes can vary widely and in order to understand how carbon is cycled and how atmospheric (CO_2) will change in the future, we needed to study the places in which carbon is stored (pools), how long it resides there and the processes that transfer it from one pool to another (fluxes). Collectively, all of the major pools and fluxes on earth comprise the global carbon cycle.

The actual global carbon transport is immensely complex. It includes every human, photosynthesizing plant, animal, and microbe. It accounts for every fallen tree, every ocean, lake, river, soil, sediment, volcanic eruptions, every breath of air and much more. This level of complexity is difficult to understand, let alone quantify. That is why scientists describe the carbon cycle by lumping together similar environments and focus on the processes that are most important at the global carbon scale. In this project, there were many factors and processes that occurred and had to be taken into consideration. Measuring soil carbon is challenging, but there are some valid assumptions that were made. First, the most prominent form of carbon in the soil is organic carbon derived from dead plant materials and microorganisms. Second, as soil depth increases, the abundance of organic carbon decreases. Making the standard soil depth testing at a max of 1 meter. This captures the dominant fraction of carbon in soils. Our testing was within the first 5 cm from the surface. There is not much research or any experimentation with carbon uptake from the side of roads, so we had to create this experiment by utilizing our research and determining the important factors to take into consideration.

In order to provide classification of all the various surface materials we test, we organized categories of the materials tested: current roadsides, inorganics, grasses, and complex landscapes. Current roadsides consisted of various ground covers including: short grass, sand, silt, and detritus material. Inorganic material included: gravel, rocks, and asphalt. Grasses involve a variety of grass types and lengths, while complex landscapes are a mixture of grass, soil, plants, and trees. The tests were conducted in a variety of locations across central Massachusetts, this was to ensure enough variety was given, while limiting the complexity of varying landscapes. We selected locations in the towns of Paxton, Shrewsbury, and Worcester, Massachusetts for testing.

4.1 Current Road Sides

In order to better understand the current state of CO_2 flux along roadways, our team set out to test three different locations at varying distances away from the road. The distances sampled were: 2.5 feet, 5 feet, and 20 feet away from the nearest roadway. On a typical roadside test, the tests being conducted at 2.5 feet and 5 feet had ground covers which consisted mostly of sand and debris from the street with very few patches of short grass. The test at 20 feet was mostly grassy with very minimal debris and patches of sand. These scenarios are relatively standard for roadway sides, seeing as nothing can be developed. It is difficult for grass to grow closer to roads, this is due to all of the chemical and sand runoff from the roads. This leads to the conclusion that the farther away from a road, the easier it is to plant grass and for the grass to survive.

In the first roadside test, at 2.5 feet away from the road, the data shows minimal flux. The soil consists of sand and silt runoff from roads and cars. While the ground cover is made up of small grass plants, as well as detritus organic material and road debris.

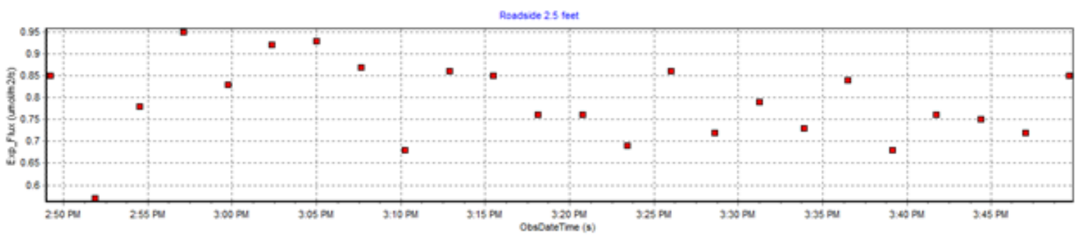

Figure 9: Roadside fluxes measured at 2.5 ft. from the pavement.

The average CO_2 fluxes for this test is: 0.792 μmol/m^2/s. These results confirm our research; inorganic material does not produce flux. Considering that our goal is to increase the amount of CO_2 flux on the side of roadways inorganic materials aren't sufficient enough. Since the material of testing is made of sand and debris, with little living or organic matter, it should have minimal CO_2 flux. Similar results are seen in our roadside test at 5 feet away from the road. The soil consists of silt and small stones with minimal patchy grass.

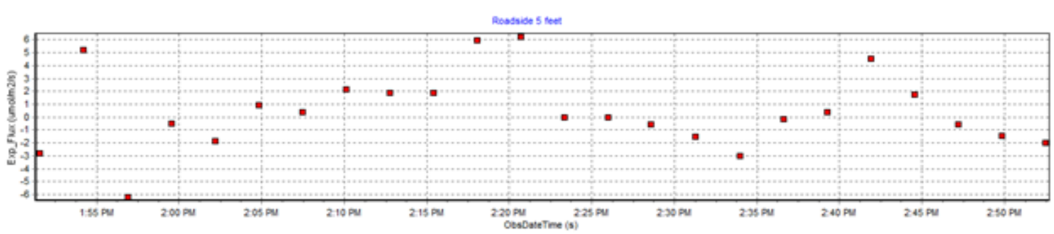

Figure 10: Roadside fluxes measured at 5 ft. from the pavement.

For this test, the average CO_2 flux is 0.445 μmol/m^2/s. Theory suggests that the farther from a road, the more flux is occurring however temperature is a factor changing the flux. The test at 2.5 feet consists of the ground temperature at 20.0°C, while the test at 5 feet temperature is: 12.7°C. Although both are above freezing, low temperatures reduce the amount of flux occurring between the soil and the air (Davidson, 2006). Which is a possible reason why the test at 5 feet had a lower average flux than the test at 2.5 feet.

The last roadside test, is 20 feet away from the road. In general, the buffer zones along roads consist of grass as a buffer to protect wildlife and help with road runoff pollutants. The testing site at 20 feet reflects these description, with very silty soil and more organic matter. The ground cover is made up of short grass that is regularly maintained and mowed.

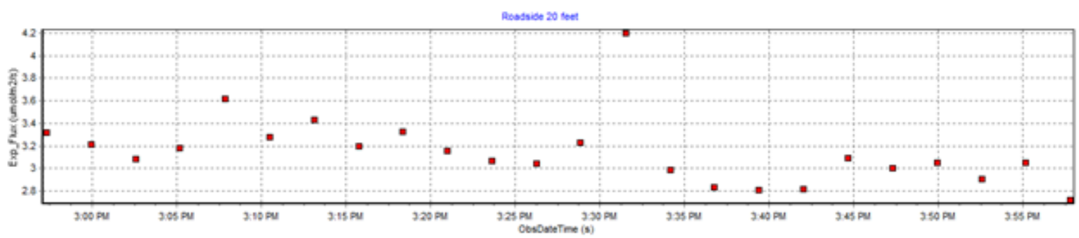

Figure 11: Roadside fluxes measured at 20 ft. from the pavement.

The overall trend of the data is more linear with less fluctuations. The average flux is: 3.151 μmol/m^2/s. It is expected that this test should yield a higher flux due to the fact that the test site was located in a grassy area, rich with carbon. Additionally, the test was performed at 13.8°C which is approximately the same temperature as the test conducted at 5 feet. Ultimately this test suggests that grass and other living biological material potentially have higher flux values than inorganic nonliving materials.

4.2 Inorganics

According to our research, inorganics such as rocks and asphalt do not sequester carbon. Organic or biological processes create some flux whether that is due to photosynthesis, respiration, or any other process involving life. Since this subset of tests involves studying non-living material there should be no flux. These tests are used as baseline tests to insure the LICOR was running properly and that the research we conducted was accurate. Gravel, rocks, and asphalt are the three inorganic surfaces that are sampled from. One negative effect of testing these surfaces is the inability to insert the soil moisture probe and thermocouple into the ground. Asphalt and rocks are impenetrable and most likely to result in damaged equipment. For these cases, temperature and moisture are ruled out because the data collection is not an accurate representation of the overall surfaces being tested. Our research shows temperature and moisture do not affect CO_2 flux because no biological processes are occurring.

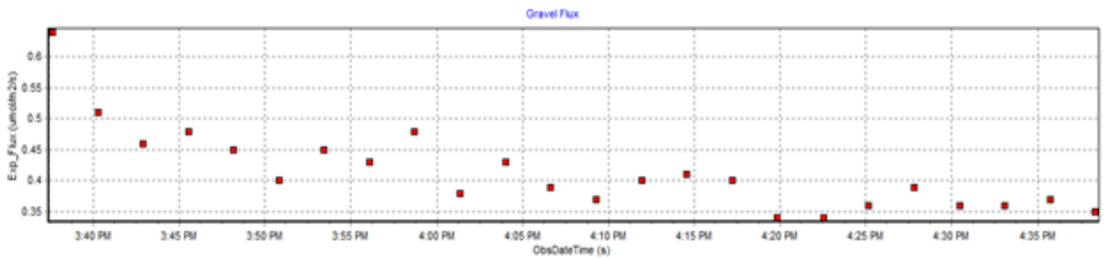

Figure 12: Gravel CO_2 flux test.

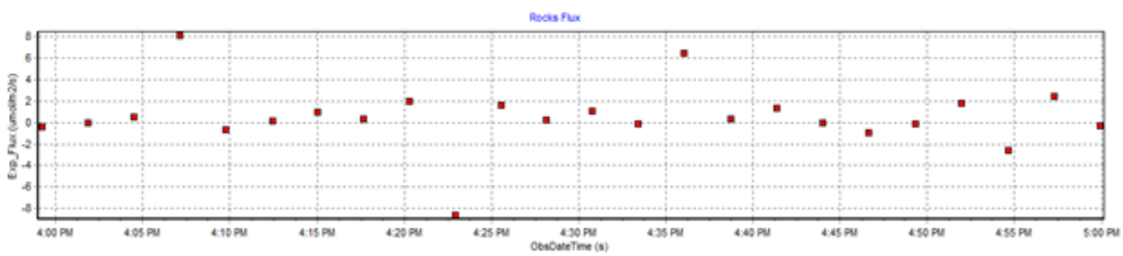

Figure 13: Rocks CO_2 flux test.

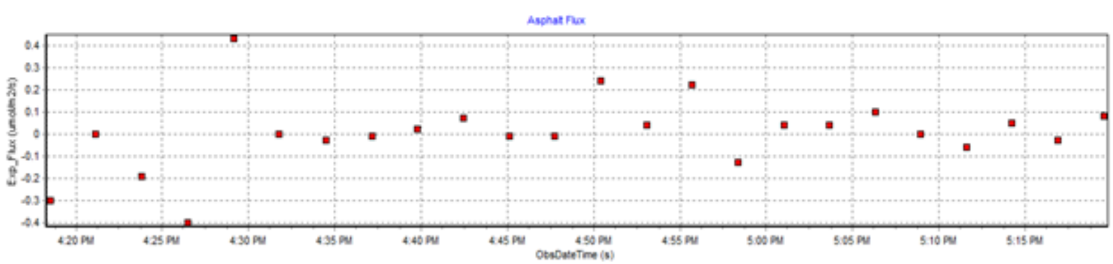

Figure 14: Asphalt CO_2 flux test.

The three graphs reflect our prediction. The data suggests that very minimal to no flux is occurring between the material and the atmosphere. There are some outliers in the data that we suspect are random errors rather than showing legitimate flux. The average flux for gravel and rock are 0.415 and 0.573 μmol/m^2/s. The areas chosen as test sites are roughly 5 square feet of the chosen material with grass or other organics surrounding them. Ideally their flux should be more like the asphalt test with an average flux of 0.007 μmol/m^2/s.

4.3 Grasses

Two different lengths of grasses were tested, along with the soil around a surrounding wetland. At these test sites we focused on the moistures and temperature of the sites. The reasoning for focusing on moisture and temperature was due to the near doubling of the temperatures and an average increase of 6 ppt in the moisture reading.

The medium grass was about 4-5 inches tall and was on the hill near the library parking lot. An average temperature was calculated 11.7°C.

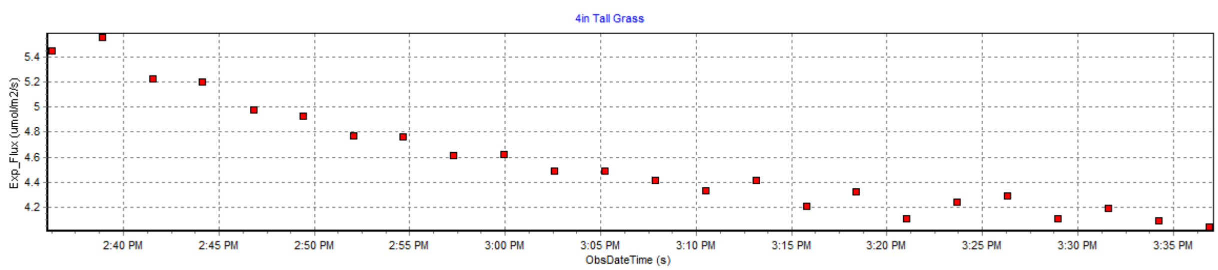

Figure 15: Flux measurements in 4-inch Grass.

From this test the average CO_2 flux was 4.8 μmol/m^2/s. The graph data is relatively consistent, with little to no drastic spikes. This grass length shows the most consistent data with no real outliers and the carbon is moving at nearly simultaneous rates between the surface and atmosphere. The grass tested was healthy and in an area in close proximity to forests, as opposed to housing and development.

The tall grass was around 6-8 inches tall and was in Moore's Park in Paxton. The site had an average temperature of 14.4˚C and an average moisture of 14 ppt.

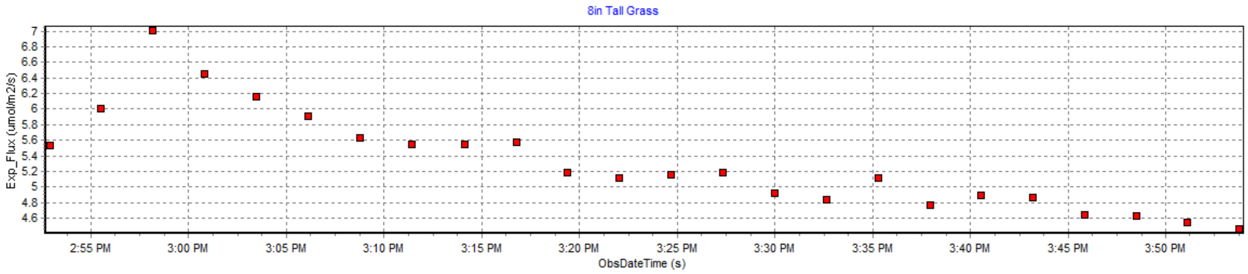

Figure 16: Flux Measurements in 8-inch Grass.

The average CO_2 flux was 7.2 µmol/m^2/s. The trend line had a 1.5 µmol/m^2/s increase in the CO_2 flux and then the data started to decrease with occasional bumps in the CO_2 flux. Overall the graph is similar to that of exponential decay with more "noise". Moisture doesn't seem to have an impact on the CO_2 flux because the graphs didn't have significant changes in relation to the moisture levels. Temperature also didn't have a significant effect in the changes in CO_2 flux.

With the wetland soil there was a large amount of detritus organic material covering the soil so that was pushed aside in our testing. Surprisingly the wetland soil didn't have the highest average moisture. The average moisture was around 9 ppt compared to the Spencer site at 2.5 ft. that had the highest moisture reading of 18.65 ppt.

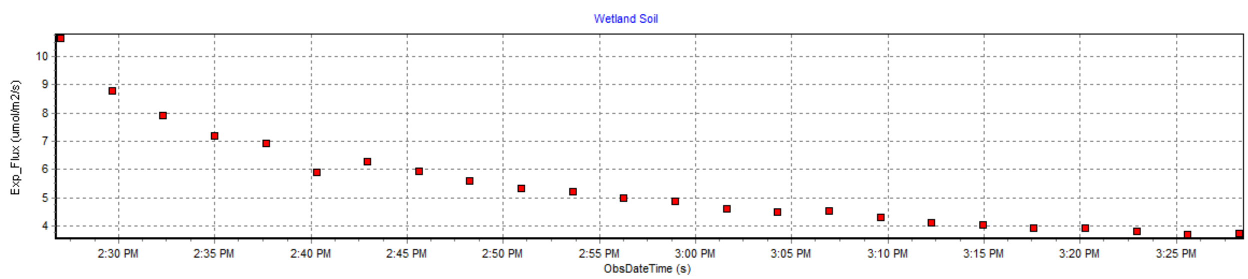

Figure 17: Flux Measurements in Wetland Soil.

For this test the average CO_2 flux was 8.8 µmol/m^2/s. This test results had the most consistent trend line with the data creating an exponential decay trend.

4.4 Complex Landscapes

The final type of land cover tested is a more complex landscape. This is due to the combined ground coverings. In particular, a variety of different decorative bed plants. These plant beds consist of a woodchip covering with different types of plants in them. The first bed tested is a large circular bed surrounding a mature beech tree. The second was a rectangular bed that contains ornamental grasses and young hydrangea plants.

At the first site, the large woodchip plant bed has an 80-foot radius and contains a 70-year-old beech tree. The test site is located towards the center of the bed to insure that no environmental error could occur. The temperature during the test was approximately 10.3°C.

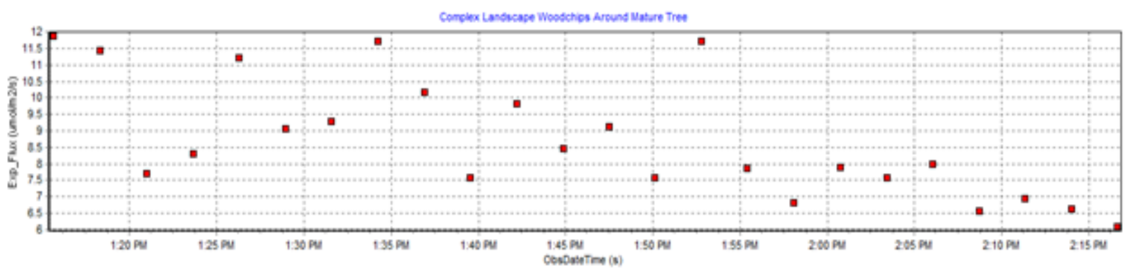

Figure 18: Flux Measurements in Complex around Beech Tree.

In this test, the average CO_2 flux is 8.726 μmol/m^2/s. Even though the woodchips are no longer producing oxygen through photosynthesis, they, as well as the tree are producing more flux than current roadsides, inorganics, and grasses. These findings correlate with our research, that trees provide the most amount of carbon sequestration.

The second complex landscape is a long rectangular woodchip plant bed with dimensions of: 35 feet by 8 feet containing ornamental grasses and young hydrangea plants. The test site is located approximately 3 feet into the bed, surrounded by ornamental grass plants. The temperature during the test was about 10.4°C.

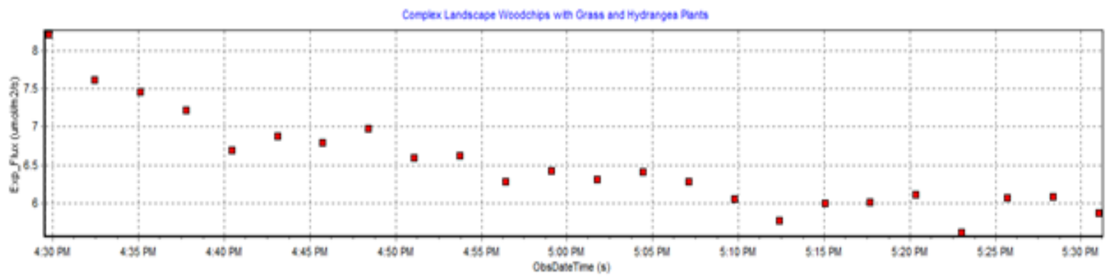

Figure 19: Flux Measurements in Woodchips.

The average CO_2 flux is 6.516 µmol/m^2/s. While the average flux is higher than some of the other test sites, it is curious that the average flux is about 2 µmol/m^2/s less than the other complex landscape site.

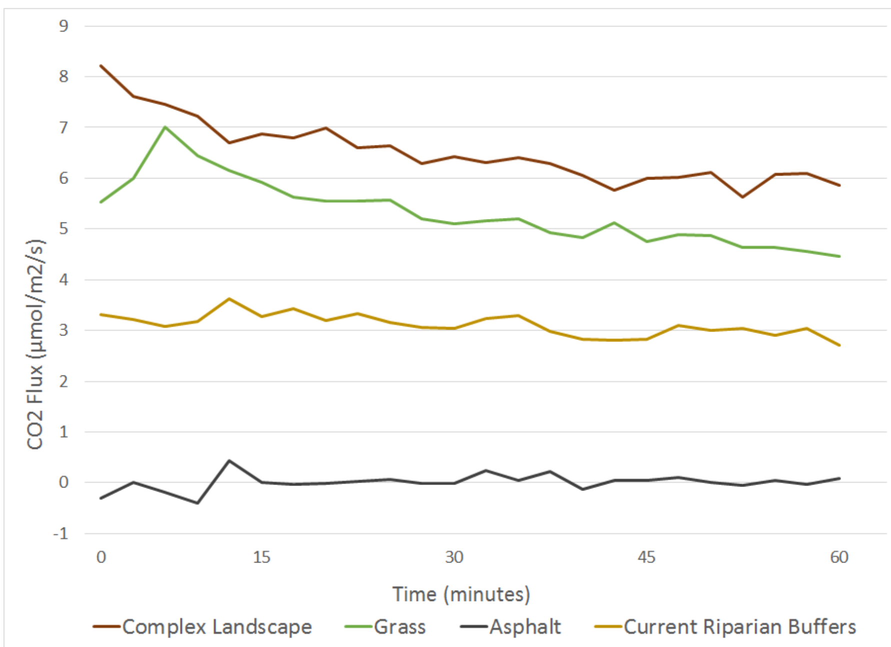

Figure 20: Compiled Data of Time vs. Carbon Dioxide Flux (µmol/m^2/s).

Figure 20 shows the trend lines of the four main groups of materials tested. It shows that complex landscapes produce the greatest flux, which gave us the necessary information to continue and design a sample buffer zone.

Chapter 5: Buffer Design

5.1 Need Statement:

According to the EPA, in 2014 the second highest contributor to greenhouse gas emissions in the United States was from transportation.

5.2 Approach

Our solution for reducing the amount of greenhouse gasses produced by cars and other vehicles was to redesign the riparian buffer zones on the sides of highways. According to the Federal Highway Administration there are over 164,000 miles of highway in the United States. From our testing we conservatively estimate that each riparian buffer zone stretches 10 feet from the edge of the highway. Which theoretically means that there is roughly 400,000 acres of riparian buffer zones in the United States.

In order to understand the current effect of riparian buffer zones we tested different ground covers for their carbon dioxide flux. Our tests consisted of three groups, current roadside groundcovers, inorganics, grasses, and complex landscapes. These groups allowed us to see the flux of different materials so that we could design a riparian buffer that would sequester the maximum amount of carbon dioxide.

5.3 Design Concept

In the first 2 feet of a buffer it is difficult to grow grasses and other vegetative material. This is due to water and chemical runoff from the road tainting the soil and choking out any form of biological life. Currently riparian zones have gravel and other road debris in the first 2 feet from the pavement surface. Gravel helps provide drainage and slow water velocity from runoff; however, gravel has no carbon dioxide flux. We suggest that instead of gravel, mulch be put in its place, covering the first 2 feet of the buffer and reaching at least 2 inches in depth. Mulch will also help to slow water runoff but it will also sequester carbon dioxide. Our testing showed an average flux of 7. 621-µmol/m^2/s, which is equal to 0.708 µmol/ft^2/s. The addition of 2 feet of mulch to every riparian buffer zone in the US would increase the total flux by 245.3 mol/s.

$$\frac{0.708\frac{\mu mol}{ft^2}}{s} \times 1\frac{mol}{1{,}000{,}000\ \mu mol} \times 164{,}000\ miles \times \frac{5280\ ft}{1\ mile} \times 2\frac{ft}{side} \times 2\ sides = 245.3\frac{mol}{s}$$

$$\frac{0.557\frac{\mu mol}{ft^2}}{s} \times 1\frac{mol}{1{,}000{,}000\ \mu mol} \times 164{,}000\ miles \times \frac{5280\ ft}{1\ mile} \times 20\frac{ft}{side} \times 2\ sides = 19{,}292\frac{mol}{s}$$

In the next 20 feet off of the highway we recommend something that has fairly minimal upkeep, is easy to grow, and fairly inexpensive: Our solution is to plant grass. Our tests concluded that the approximate CO_2 flux for grass between 4 and 8 inches tall is 6. 0-µmol/m^2/s, which is equal to 0.557 µmol/ft^2/s. The addition of 20 feet of grass between 4 and 8 inches to every riparian buffer zone in the US would increase the total flux by 19,292 mol/s.

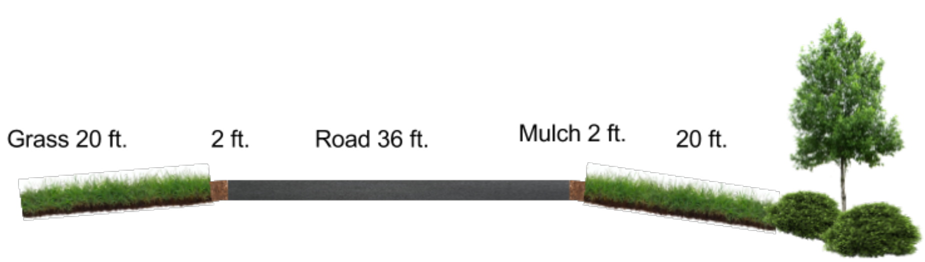

Figure 21: Buffer Zone Design.

After the 20-foot strip of grass we recommend planting trees, shrubs, and other large forms of vegetation. Currently many of riparian buffers have trees and shrubs located 20 feet away from the highway. Trees and shrubs are low to no maintenance and absorb a significant amount of CO_2. Forests, grasslands, and shrub lands sequester hundreds of millions of tons of carbon dioxide each year, and the ecosystems they create account for roughly 95 percent of the carbon dioxide sequestered year round (Study of Carbon Storage and Sequestration). The addition of more trees and shrubs will allow larger ecosystems to develop and flourish, increasing the overall carbon dioxide sequestration seen in riparian buffer zones.

5.4 Cost Estimates

The major costs of our design will stem from the purchase and shipping of wood chips, the purchase and planting of grass seed, and the purchase and planting of trees and shrubs. The cost estimates are based on a 100-foot-long section of highway. All labor costs will be an assumed $20.00/hour. The mulch layer will be hand spread to ensure greater accuracy than with heavy machinery and to reduce overall equipment costs. The two-foot-wide, two-inch-thick, 100-foot-long layer will require 1.234 cubic yards of mulch. Shredded log mulch for this area would cost roughly $23.50 per section of highway, with shredded log costing $19.00 per cubic yard (homeadvisor.com). The 20-foot-wide grass area will need to be seeded with native grass seed. Native grass is capable of surviving in warm and cold temperatures, reducing the need to replant frequently. A single 5-pound bag will cover each 2,000 square foot section, costing between $110.00 and $170.00 per bag, depending on the desired quality (seedland.com). Lastly, assuming no trees or shrubs already exist in the buffer, the purchasing and planting of seeds will be necessary. There are many factors to consider when planting trees, and depending on the condition of the environment planting may begin with seeding or slightly aged saplings and juvenile trees. The average cost to plant one tree is about $167.00. When planting more than 5 at a time, the price per tree drops to around $138.00. The amount of land that this final layer will use is likely to vary depending on location, so it is difficult to make a concrete estimate of how much each 100-foot section of highway will cost. At its cheapest, 5 hours of work on a single 100-foot-long section of highway will cost around $1,613.50

Chapter 6: Conclusions

6.1 Approach

Our first goal for approaching the project was to determine which environmental factors we wanted to isolate as variables in our experiments. Nearly every aspect of the environment, involves carbon, making it difficult to find trends that correlate to each individual factor. Our idea was to test with variables that could be easily measured and quantified while keeping as many others as constant as possible. After ruling out variables that we could not control, such as microbial activity and weather patterns, we decided to isolate moisture level, temperature, and ground coverage (grass, rocks, etc.). Temperature and moisture were within the realm of measurable variables and both have notable impacts on carbon flux in soils. We chose ground coverage so as to compare possible suggestions for how to recreate buffer zones in the future.

In order to accomplish this, we restricted our measurements to similar times of day and distances from the road. We kept as many other variables constant as we could and used additional measurement tools to keep track of soil temperature and soil moisture throughout the testing period. This process gave us accurate temperature and moisture readings alongside the carbon flux measurement. We then searched for sites with reasonable variation in ground cover. We searched various towns in Massachusetts and found several different examples of common ground cover, including naturally growing grass and wetlands. From here we were able to schedule our tests to fall within the same two-hour period to avoid large differences caused by the time of day. While there was no way to control some of the variables that impact carbon sequestration, we were able to focus our measurements enough to discern relationships between our chosen variables and carbon flux rates.

6.2 Expectations of Tests

Our general expectations were that we would see different carbon flux rates between the different surfaces we tested. For example, we expected to see much higher flux in grassy areas where the grass and microbes in the soil would both be actively photosynthesizing and respiring. For other surfaces like rock and pavement, we expected to see little to no flux at all. While it is likely that these surfaces absorb small amounts of atmospheric CO2, the lack of biological processes to either absorb or produce more makes it unlikely that there will be any significant flux. In our research on the topic, we found that an increase in biological matter corresponded with increased flux rates, both positive and negative.

There were several trends that we were expecting to see in the data from our measurements. More specifically than just different surface materials, we were hoping to find variations that correlated with temperature and moisture levels. Trends in these variables would impact our overall idea of how environmental factors impact flux on an individual level. While we did not know how temperature and moisture would change flux initially, we were expecting that higher levels of each would result in more drastic flux overall. Ultimately, we expected trends that would allow us to make further inferences on how our variables impacted flux directly, whether it increased the movement of CO_2 out of the ground or caused more to move in.

6.3 Analysis of Results

Out of the 11 test sites we conducted we have grouped each testing sites into four groups: current roadsides, inorganics, grasses/organics, and complex landscapes. In the current roadside group three distances were measured in order to obtain a better understanding of how CO_2 flux changes with the distance from the roadsides. The inorganics group was used in determining a baseline for the CO_2 flux to which we compared the other data obtained from the rest of the testing sites. Grasses/organic materials are the typical materials found on the side of roadways. Grass is one of the most common roadside materials that you will typically find along the road. Since grass is so common we decided to measure two different lengths of grass, medium (4-5 inches) and long (6-8 inches) long. The last group is complex landscapes and we chose to examine them because of the multiple types of materials that are used for coverings. Although these materials aren't found alongside highways we thought that they might have large amounts of CO_2 flux. From the data collected we have come to a conclusion to the types of materials that generate the most and least amounts of CO_2 flux.

The materials that generated the most CO_2 were the grasses/organics, with an average flux of 8 μmol/m^2/s. In general, the grasses and organic soil have the highest average CO_2 flux out of the four groups of materials. This is expected due to plants photosynthesizing throughout the day unlike the inorganics that just have microorganisms in the soil or surrounding area that would generate miniscule amounts of CO_2 flux and this flux is created through organic and biological processes that occur in grasses and organic materials. The material that created the second highest amounts of CO_2 flux was the complex landscapes. Although woodchips do not photosynthesize and respire they absorb more CO_2 flux than current roadside immediate buffers. Current roadsides are constantly being endowed with chemicals and runoff from the ongoing traffic. That being said current roadsides isn't the group that produces the least amount of CO_2 flux.

Inorganic materials such as gravel, rocks, and asphalt produce the least amount of CO_2 flux with an average of 0.332 μmol/m^2/s. The reasoning for the average flux being 0.332 μmol/m^2/s instead of closer to the asphalt test of .007 μmol/m^2/s could be due to environmental errors, however, the average flux for inorganic materials should have been closer to the asphalt test because no organic or biological processes should be occurring.

6.4 Observed Trends

Our research prior to conducting field tests notes that temperature is a factor in organic materials with the ability to create flux, however our data proved to be inconclusive with regard to temperature. Theory suggests that plants are most active in warmer weather conditions, however since our data was taken in the fall and under a minimal temperature variation, the lowest temperature recorded was 3°C and the highest was 21°C. While that is still a range of 18°C, plants become dormant in the fall and slow down their photosynthesis thus reducing their flux. Additionally, our testing methodology was flawed in order to test for temperature trends. We collected data from each location once, if we wanted to see what impact temperature played in CO_2 flux we would need to test a location multiple times at different temperatures.

Although our tests could not directly correlate temperature variations with carbon dioxide flux, our tests do show fragments of diurnal flux. Each test was run for an hour in the afternoon, and over the course of that hour the flux decreased showing that the biological material was fluxing less as it became almost night. In order to more concretely test for diurnal flux, longer tests would be required highlighting the theoretical maximum around noon and a minimum in the morning and night.

Literature also suggested that soil moisture would impact flux due to its interplay with microbial organisms and other organics, however our data was unable to support that. The literature suggests that too little or too much moisture in soil will kill microbial organisms while a normalized amount will lead to normal biological processes. While our tests did include taking soil moisture readings, in a similar way to why we were unable to prove temperature as being a factor, each site was only tested once. In order to better understand what water does to CO_2 flux we would need to test each site at different moisture concentrations.

When testing various forms of grasses, the data showed far fewer outliers than the other test locations. The lack of noise in the data could point to many different things. In general, it means that the CO_2 flux was more consistent. Many different factors play into this, easier installation of the soil collar, larger test locations, and various environmental and human factors. Installing the soil collar for the grass tests was often easier due to the soil being lower in rocks and overall softer due to the higher level of organic matter; this could mean that there was less interference or error in the test from outside the chamber environment. Additionally, tests that were conducted in rockier soils were harder to install the soil collar, which could lead to outside interference and error.

6.5 Further Testing

This project is a worthwhile endeavor to pursue and there are various approaches on how to continue testing and conducting experiments for this project. The team unanimously decided one factor that needs to be experimented with more is the season of testing. Due to limiting circumstances, our team was only able to test carbon dioxide flux in the months of October and November. While this is an accurate representation of a carbon rich time, the carbon flux will be different in warmer months of spring and summer. The type of surface material we were able to test was also limited. Testing other material may prove beneficial to find other covers that create a greater flux. For our design in particular, it would be beneficial to test if different types of wood chip mulch and grasses create different fluxes to target the best of the grass types and mulch.

For a more economical and project approach, engineering a way to actually implement this and make it a possibility with the basis we have started. This idea can be improved upon by more time and testing and if an adequate plan was implemented, it would be feasible approach to carbon sequestration. The primary concerns of the plan include the cost and maintained associated with implanting this plan, as well as the feasibility in compared to rate of return. It is a balance between investment and outcome, will this investment be a worthwhile investment? Is there enough accurate data to support this?

We have been only given one earth and by our need for energy, we burn fossil fuels to survive, this burning releases the carbon dioxide that is what contributes to the think blanket that heats up our earth and keep it warm. The solution would seem simple, stop burning fossil fuels and releasing so much excess carbon into the atmosphere. However, this is not as simple as one thinks, we are given this earth and it already has a natural system for sequestering carbon dioxide. It was our project to engineer a way to utilize the resources found naturally to help solve a serious world problem. Our solution, while simple is also complex, with theory and data to support behind it. That if we implement this design across highways buffer zones, then a significant amount of carbon dioxide will be removed from the atmosphere.

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Appendix A: Field Notes

WPI	**Field Note Sheet**	
Field Testers: ARMS, MAM, NPS, AMS	**Location: Shrewsbury, Worcester Turnpike 42.2777 lat, -71.6961 long**	**Site No: 1**

Photo No: 1	**Date:** 10/29/16	
Description: Vegetation around the collar appears to be withering, soil contains half-inch stones.		
Photo No: 2	**Date:** 10/29/16	
Description: Test site was located 5 feet from the road. Traffic was moderate.		

Field Note Sheet

Field Testers: ARMS, MAM, NPS, AMS	**Location: Shrewsbury, Worcester Turnpike 42.2777 lat, -71.6961 long**	**Site No: 2**

Photo No: 1

Date: 10/29/16

Description:

Medium length grass in and around the soil collar. Vegetation did not appear to be in full bloom.

Photo No: 2

Date: 10/29/16

Description:

Test site was located 20 feet from the road, slightly down gradient from Test Site No. 1. Traffic was moderate.

Field Note Sheet

Field Testers: ARMS, MAM, NPS	Location: Institute Park, Worcester 42.2788 lat, -71.8074 long	Site No: 3

Photo No: 1 **Date:** 11/5/16

Description:

Moist organic soil in and around the collar.

Photo No: 2 **Date:** 11/5/16

Description:

Test site was located within roughly 2 feet of the edge of a pond. It was also approximately 80 feet from the nearest road, which has slim to no traffic.

WPI Field Note Sheet

Field Testers:
ARMS, MAM, NPS

Location: Institute Park, Worcester
42.2785 lat, -71.8078 long

Site No: 4

Photo No: 1

Date:
11/5/16

Description:

Soil was sandy and contained a large amount of gravel. Soil was generally dry.

Photo No: 2

Date:
11/5/16

Description:

Test site was located on a gravel pedestrian walkway up gradient from Site No. 3. Site was also approximately 100 feet from the nearest road, which has minimal traffic.

WPI	Field Note Sheet	
Field Testers: ARMS, MAM, NPS	**Location: East Hall, WPI, Worcester MA 42.2736 lat, -71.8052 long**	**Site No: 5**

Photo No: 1	**Date:** 11/12/16	
Description: Soil inside the collar was comprised mostly of wood chips and dead leaves. Dying ornamental grass plants surround the soil collar. Soil was fairly dry		
Photo No: 2	**Date:** 11/12/16	
Description: Test site was located adjacent to a cement pedestrian walkway in a flowerbed comprised of ornamental grasses. Site was also approximately 50 feet from the nearest road, which had minimal traffic.		

WPI

Field Note Sheet

Field Testers: ARMS, MAM, NPS	Location: WPI Beech Tree Circle, Worcester 42.2736 lat, -71.8085 long	Site No: 6

Photo No: 1

Date: 11/19/16

Description:

Soil was comprised of mostly organics. Roughly two inches of woodchips, decaying leaves, and sticks covered the soil. Soil was fairly moist to the touch.

Photo No: 2

Date: 11/19/16

Description:

The test area was comprised of a mulched circle with a diameter of 80 feet with a large beech tree in the center. The test site was approximately 15 feet away from the nearest road.

WPI	**Field Note Sheet**

Field Testers: ARMS, MAM, NPS, AMS	**Location: Paxton, MA 42.3075 lat, -71.9846 long**	**Site No: 7**

Photo No: 1	**Date:** 11/26/16

Description:

Ground was covered in mixed sized riprap stones. Soil color was placed over riprap stones, however the team noted that there was not a complete seal between the soil collar and the ground therefore tests could show outside error.

Photo No: 2	**Date:** 11/26/16

Description:

The test area was comprised of mixed size riprap. Some dead vegetation rose to the surface through the spaces between the stones. The test site was approximately 10 feet away from the nearest road with moderate traffic

WPI

Field Note Sheet

Field Testers: ARMS, MAM, NPS, AMS	**Location: Paxton, MA** **42.3075 lat, -71.9846 long**	**Site No: 8**

Photo No: 1

Date: 11/26/16

Description:

Ground was comprised mostly of sand and small stones. Minimal vegetation was observed in the test area. Soil felt dry to the touch.

Photo No: 2

Date: 11/26/16

Description:

This test was conducted approximately 2.5 feet away from the nearest road. Test site consisted of mostly sand with some dead vegetation roughly 3 feet off the road. The road had steady traffic.

Field Note Sheet

Field Testers: ARMS, MAM, AMS	Location: Moore State Park, Paxton 42.3103 lat, -71.9537 long	Site No: 9

Photo No: 1

Date: 11/13/16

Description:

Ground was comprised mostly organics. Long grass roughly 8 inches covered the soil. Decaying leaves from trees covered the grass. Soil felt slightly damp to the touch.

Photo No: 2

Date: 11/13/16

Description:

This test was conducted in the middle of a field at Moore State Park in Paxton. The test site was approximately 150 feet away from the nearest road.

Field Note Sheet

Field Testers:	Location: Worcester, MA	Site No: 10
MAM	42.2733 lat, -71.8042 long	

Photo No: 1 **Date:** 12/2/16

Description:

Surface was comprised of asphalt. This test was conducted to see if the same material that roads are built out of would produce any flux.

Photo No: 2 **Date:** 12/2/16

Description:

This test was conducted in the middle of a small parking lot approximately 10 feet away from the nearest road with moderate traffic.

Logo	Field Note Sheet	
Field Testers: ARMS, MAM, NPS	**Location: Boynton Street Parking Lot 42.2733 lat, -71.8060 long**	**Site No: 11**

Photo No: 1 **Date:** 11/12/16

Description:

Surface was covered in grass roughly 3 inches in length. Due to the season, the grass is starting to become dormant and some grass is dead.

Photo No: 2 **Date:** 11/12/16

Description:

This test was conducted on a hillside adjacent to a parking lot. The test site was located roughly 10 feet away from the nearest road.