New York State Energy Research and Development Authority

Mitigation of Ecosystem Degradation by Bioenergy Using Biochar

Final Report

June 2012

Report Number 12-19

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nyserda

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Mitigation of Ecosystem Degradation by Bioenergy Using Biochar

Final Report

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Acronyms and Abbreviations

° C	degrees Celsius
° F	degrees Fahrenheit
µmol	micromoles
Btu/scf	British thermal unit per square cubic foot
C	carbon
Ca	calcium
CEC	cation exchange capacity
CH_4	methane
cm^3	cubic centimeters
CNMP	Comprehensive Nutrient Management Plan
CO_2e	carbon dioxide equivalent
cu yd	cubic yard
DEC	Department of Environmental Conservation
DDGS	Distillers dried grains with soluble
g	grams
GHG	greenhouse gas
K	potassium
kg	kilogram
kWh	kilowatt hour
Mg	magnesium
mL	milliliter
mM	millimolar
mmol	millimoles
MMtCE	million metric ton equivalent
MSW	municipal solid waste
Mt	metric ton
MWe	megawatt equivalent
N	nitrogen
Na	sodium
NO_x	nitric oxides
NY	New York
NYS	New York State
RGGI	Regional Greenhouse Gas Initiative
sq ft	square feet
syngas	synthesis gas
t or ton or tonne	metric ton
UNFCCC	United Nations Framework Convention on Climate Change
USDA	U.S. Department of Agriculture
USGA	U.S. Golf Association

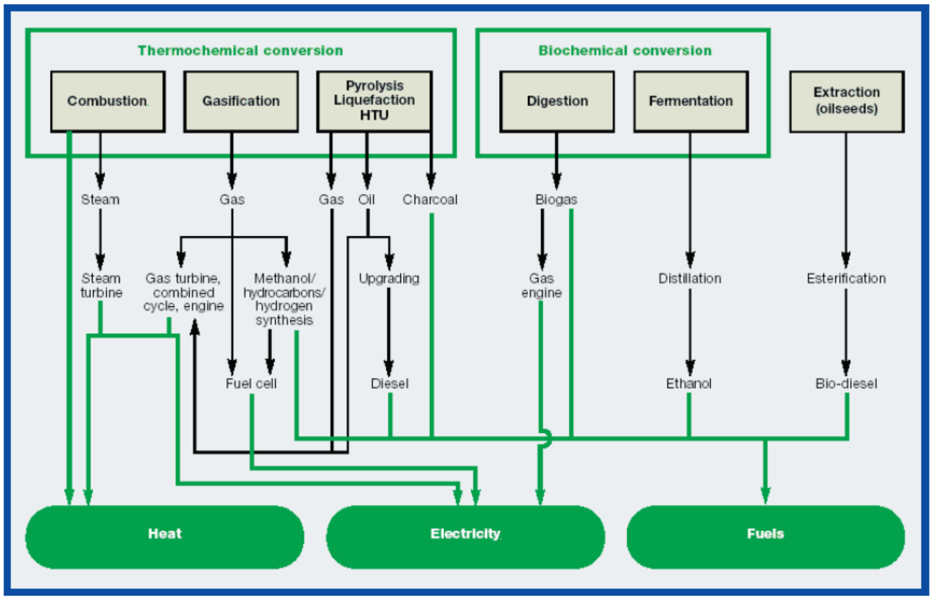
Executive Summary

The growing awareness of the link between climate change and the burning of fossil fuels has lead to an increased interest in identifying sources of renewable energy. Bioenergy, produced from renewable biomass, is one such form of energy. Biomass refers to living and recently living biological material. It includes dedicated energy crops and trees, food and feed crops, crop wastes and residues, wood wastes and residues, aquatic plants, animal wastes, organic-based municipal and industrial wastes, and other organic-based waste materials. As biomass grows, it draws carbon dioxide (CO_2, a greenhouse gas) from the atmosphere. If biomass is allowed to degrade anaerobically (i.e., in the absence of oxygen), methane (CH_4), a potent greenhouse gas, may be produced. Therefore, the use of organic wastes as a feedstock in the energy production process not only eliminates the combustion of fossil fuel, but may also eliminate the production of CH_4. Biomass can be converted to an array of energy-related products including electricity; heat; and liquid, solid, and gaseous fuels. These biomass-derived products are considered renewable due to their photosynthetic origin. The products are produced using a number of processes, including microbial fermentation, extraction of oils from crops, pyrolysis and gasification of biomass (Caputo et al. 2005). These routes and energy products associated with a number of conversion technologies are summarized in Figure 1.

The focus of this project was slow, low-temperature pyrolysis, a thermochemical process where biomass is heated in the absence of oxygen. Synthesis gas (syngas), oils and biochar are by-products of pyrolysis. Biochar is very stable compared to uncharred biomass (Baldock and Smernik 2002; Lehmann et al. 2006). Based on applied field research (Lehmann et al. 2003a; Rondon et al. 2007), as well as observations of lands where biochar was historically applied (Lehmann et al. 2003b), biochar can act as a soil conditioner; enhance plant growth; improve the physical and biological properties of soil (Glaser et al. 2002); provide nutrients to and retain them within soil; and reduce off-site effects such as runoff, erosion and gaseous losses.

Figure 1. Technologies and energy products for bioenergy production

Source: IAEA. 2007. Potential Contribution of Bioenergy to the Worlds Future Energy Demand. http://www.ieabioenergy.com/MediaItem.aspx?id=5586.



Pyrolysis to produce energy and biochar represents an exciting opportunity to match society's needs for energy and food. It also has the potential to deliver negative greenhouse gas emissions. This approach can be modeled under a number of scenarios; the following three were identified through this project:

- Model 1 - A pyrolysis plant located at a municipal facility processing yard waste.
- Model 2 – A pyrolysis plant located at a large institutional facility processing compostable organic wastes.
- Model 3 - A pyrolysis plant for processing animal wastes.

Model 1 underwent a thorough analysis that suggested that a pyrolysis plant located at a municipal facility that processes yard waste would be financially viable in New York State based on estimated revenues derived from tipping fees, sale of the resultant biochar (for turf grass, wetland construction, and high value agricultural applications), carbon trading revenues, and sale of produced electricity. Additionally, the Model was found to deliver carbon negative, renewable energy with a sequestration potential of at least 11.7 Million Metric Tons per Carbon Equivalent.

The project described within this document was comprised of seven tasks, the first of which was Project Management. The work performed under the other six tasks is the subject of this report. The six tasks were:

- Task 2: Design of Conceptual Models for a Viable Biochar Bioenergy System in New York State
- Task 3: Feedstock Availability and Biochar Production Conditions
- Task 4: Improving Soil Fertility
- Task 5: Nutrient Leaching from Soils
- Task 6: Agronomic and Environmental Impacts
- Task 7: Refining the Conceptual Models

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1 Task 2: Design of Conceptual Models for a Viable Biochar Bioenergy System in New York State

A wide range of process conditions can be optimized to influence the type and nature of by-products from the pyrolysis process (i.e., feedstock, temperature, heating rate and pressure); however, all processes generate some amount of char (also referred to as biochar or agri-char) as well as synthetic gas (syngas). [Note: syngas is composed of combustible gases including hydrogen, carbon monoxide, methane, and lower molecular weight hydrocarbons, as well as nitrogen and carbon dioxide. Some of the generated syngas is typically combusted and used as a heat source for the pyrolysis system; some is combusted and used to dry the incoming feedstock. The remaining syngas can be used as a fuel for an engine, industrial boiler or a down-stream processes (i.e., refined into chemicals or liquid fuels).]

Pyrolysis systems are typically designed either for production of a specific by-product (i.e., liquid oil or biochar) or ability to handle a particular feedstock material (i.e., high ash waste stream). Slow, low-temperature pyrolysis offers the distinct advantage that the process can be optimized for the recovery of biochar. Additionally, the process temperature parameters used avoid the formation of polyaromatic hydrocarbons in the biochar product (Downie 2007). The key features of slow pyrolysis are summarized in Table 1. To date, the bulk of biochar used in soil amendment research studies has been derived under conditions of slow, low-temperature pyrolysis.

Slow pyrolysis is a flexible technology that can use a wide range of feedstocks. In broad terms, any biomass stream that is considered as compostable or digestible is likely to represent a potential feedstock. However, given the goal of this project was to produce a biochar that could safely be applied to land, the feedstocks were somewhat limited. Therefore, the study focused on biogenic and agricultural wastes that are unlikely to pose any significant risks of contamination. Feedstock availability is a key factor affecting the economic viability of such systems. Therefore, the study also focused on feedstock streams that currently represent a cost to the producer or handling agency, so that a facility could anticipate receiving a tipping fee for these streams.

The models described in this report are based on a slow pyrolysis technology provided by BEST Energies Inc. (www.bestenergies.com). In all of the models, the syngas is used for energy generation, because this use is well proven and understood. However, options are being developed for using the syngas as a feedstock for downstream processes.

1.1 Pyrolysis Feedstocks

A variety of potential feedstocks, available in New York State (NYS), are discussed below including yard waste, renderers waste fines, paper waste, distiller grains, and manure. Case studies follow. Case Studies 1 through 3 are based on yard waste. Case Study 4 describes a scenario based on renderer's fines. Case Study 5 describes a scenario based on a paper mill that uses recycled fiber and segregates their waste stream for alternate disposal routes. Case Study 6 describes a scenario where an agricultural facility produces compost and other high value products.

1.1.1 Yard Waste and Compostable Waste Streams

Yard waste is a significant and widely available feedstock stream comprised predominantly of leaves, grass clippings and trimmings. The composition and moisture content of yard waste varies throughout the year. Yard wastes are produced wherever there are residential developments. Often this waste is disposed of in landfills, at clearly established tipping fees, where it breaks down under predominantly anaerobic conditions to produce methane (CH_4, an emission that can be avoided). State-level statistics on the amount of yard waste generated yearly were not available. However, the 37 permitted NYS yard waste facilities handle an estimated 400,000 tons per year (Lim 2007).

Table 1: Key features of the slow pyrolysis technology.

Feature	Description
Feedstock flexibility	Pyrolysis systems can process a diverse range of biomass types; materials that may vary widely in size from dust to chunks. Fuel with up to 50% water can be processed; high moisture fuels are pre-dried.
Process control	Indirect heating of the pyrolysis kiln means that the temperature of the material being pyrolyzed can be carefully controlled to maximize yields of char, gas and liquids, some of which are subsequently cracked to syngas.
Low temperature process [400-600°C]	Low-temperature pyrolysis reduces the amount of inorganics (metals and their compounds),, which are volatilized, compared to higher temperature processes.
No dioxin formation	Dioxins are created when organic compounds react with chlorine in oxygen, and the reactions are catalyzed by metals such as copper.
No NO_x formation in the reactor	Pyrolysis does not give rise to NO_x. In gasification and combustion, NO_x levels cannot be controlled because the addition of oxygen to the process leads to local high particle surface temperatures, giving rise to volatile metals,and formation of thermal NO_x.
Higher electrical efficiencies than gasification and/or combustion	Pyrolysis for electricity production at small scale (i.e. 2-5 MWe) is more efficient than combustion+ steam cycle. Downdraft gasification is limited for electrical output above 500 kWe, and requires multiple modules. Updraft gasification is available from 2.5 MWe, but tar handling issues make the process complicated, expensive, and lower overall efficiency [18-23%]. Fluid bed gasification is only efficient when operated as a Integrated Gasification Combined Cycle with a net efficiency of 32% at 6 MWe output. Combustion + steam cycle has a maximum 20% efficiency for advanced configurations. Pyrolysis can achieve electrical efficiencies from dry feedstock of 20-27%, depending on the engine used, amount of char produced and the feedstocks moisture content. Gasification can achieve similar conversion efficiencies at less than 500 kWe, but have not been adequately proven from 2 - 5 MWe.
A syngas with multiple uses	The syngas with a heating value of 135-290 Btu/scf from the process can be used for: • Heat generation in boilers. • Co-firing with natural gas into gas turbines. • Synthesis of liquids transport fuels. • Power generation in engines and turbines.
Scaleability	Pyrolysis kilns are more easily scaleable than downdraft gasifiers and compete on cost with updraft and fluid bed gasifiers up to 5 MWe.

Representative costs for disposal of yard waste are shown in Table 2. The estimated cost for disposal ranges between $55 and $80 per wet ton. In Tompkins County's, a significant proportion of this cost is a gate fee paid either to the landfill or composting facility. For Suffolk County, the fee is paid to contractors who remove the waste. Based on research performed to date, it appears that a fee on the order of $35 to $60 per wet ton can be justified. However, in Delaware County, the higher cost may be justified if the waste stream is more complex than standard yard waste.

Table 2: Summary of gate fees and costs of disposal for yard waste.

County	Facility Gate Fee	Other Costs ($ / t wet weight)		Total Costs ($ / t wet weight)
Suffolk County	NA	Disposal Contract	$ 55-70.00	$55-70.00
Tompkins County	$35-37.50/US ton	Transport	$ 22.00	$57-59.50
Delaware County	NA	Capital & operating costs	$ 83.00	$83.00

1.1.1.1 Case Study 1: Suffolk County - Pay to dispose of yard waste

Of the 10 towns in the county, the seven towns in the western part of the county each produce a minimum of 25,000 tons of yard waste annually (DesGains 2007). The yard waste is bagged and trucked to an out-of-state landfill or to a composting facility (upstate or out-of-state) with a transport/disposal fee of $55-$70/ton.

1.1.1.2 Case Study 2: Delaware County – Operate a composting facility

The solid waste authority uses an innovative system to reduce the volume of organics it landfills. Mixed municipal solid waste (MSW) is trucked to a 700-ton holding tank, where it is processed via Rotary Digestor Technology. After three days, the waste is screened; the waste remaining on top of the screen is sent to the landfill. Wastewater treatment biosolids are mixed with the remaining waste and aerated for 56 days. The finished product (Oxbow Hollow Compost) is bagged/sold for $10/cubic yard (cu yd). The site processes 36,000 tons of mixed MSW and 6,500 tons of biosolids yearly. The cost of constructing the facility was approximately $20 million, and yearly operating costs are approximately $1million. Assuming a 10 year life span, using the facility represents a cost of approximately $83 per ton of waste, not including the revenues derived by the sale of Oxbow Hollow Compost.

1.1.1.3 Case Study 3: Cayuga Compost – Commercial composting facility

Cayuga Compost is a privately run operation that collects materials from various sources throughout the county. In 2007, approximately 1,850 tons of material were composted, resulting in approximately 2,500 cu yd of compost. The compost is dry, recognized as high quality, and is sold for $40/cu yd. Wood chips are used to aerate the compost piles, which reduced the amount of turning required, and are removed prior to selling the compost (and re-used). The energy associated with screening equals the energy avoided with less reduced turning). The feedstocks to the system include:

- **Yard wastes** – two-thirds of the materials are obtained through a contract with Tompkins County Solid Waste, who collects residential yard wastes at a transfer station and trucks it to Cayuga Compost (700 - 800 tons/year). Wastes derived from landscapers and arborists are also accepted for a $37.50 per ton tipping fee.
- **Farm wastes** - Primarily horse bedding; manure and bedding made from softwood , hardwood, straw (approximately 250 tons/year).
- **Food wastes** - Universities, restaurants, grocery stores, schools and festivals contribute a total of approximately 1000 tons/year.

1.1.2 Renderer’s Fines

The animal rendering industry offers a potential feedstock stream for pyrolysis systems due to the fact that they manufacture yellow grease (from spent restaurant fryer oil). Solids are strained from the oil prior to rendering, and the accumulated “grease fines” represent a burdensome waste stream for the rendering facilities. NYS produces approximately 180 million pounds of yellow grease annually. However, the amount of renderer’s fines produced by an individual yellow grease producer is not sufficient to warrant dedicated pyrolysis facilities for each producer.

1.1.2.1 Case Study 4: Baker Commodities, Inc. – Manufactures a rendered waste stream

Baker Commodities, located in Rochester, N.Y., manufactures rendered waste streams to marketable products. Baker collects waste oils at four facilities from restaurants throughout the State, which are operated as transfer stations to the main site in Rochester. Baker produces approximately 10 tons per week of grease fines, which are sent to a landfill at a tipping fee of $50 per ton.

1.1.3 Distillers Grains

Distillers dried grains with solubles (DDGS) are produced as a by-product of ethanol production. According to ethanolrfa.org, “a modern dry-mill refinery can produce 2.8 gallons of ethanol and 17 pounds of DDGS from 1 bushel of corn.” In 2006, 85 percent of all DDGS produced went to the beef and dairy industries; 9 percent to the swine industry; and 3 percent to the poultry industry. With the planned expansion of capacity for ethanol production, future projected uses for DDGS include packaging material, litter, food additives and fertilizer.

A concerted effort has been put forth by the industry to establish recommended testing protocols for laboratories to determine the moisture, crude protein, crude fat and crude fiber of DDGS. These factors often determine the market value of the DDGS and are also important for assessing the feedstock’s efficiency for pyrolysis. Historically the lack of an established protocol has led to results varying significantly between laboratories. As of 2008, there were three plants planned, under construction, or in the initial years of production in NYS:

- Northeast Biofuels (Volney, N.Y.) - Investors planned to convert an old Miller Beer brewing site to a corn ethanol generation plant. The plant planned on marketing the wet and dried distillers grains through Perdue's animal protein division, Venture Milling (www.nebiofuels.com, www.permolex.com). It was estimated that the facility would produce 2,411,765 pounds (1,093,958 kilogram) of distillers grains per year.
- Empire Biofuels (Seneca Falls, N.Y.) - Conceptualized by a NYS corn growers consortium, this plant was projected to produce 175,000 tons of distillers grain annually.
- Western NY Energy, LLC (Shelby, N.Y.) – According to the company's website (www.wnyenergy.com), the company planned to sell both wet and DDGS, and was projected to produce 88,000 tons of distillers grain annually.

As of 2008, the business models for these plants relied on the sale of distillers grains as a product, primarily animal feed. However, discussions with staff at Cornell University indicate that any one of these plants is likely to meet the needs of the feed market in NYS. Therefore, co-location of a pyrolysis facility alongside an ethanol plant may be attractive. The pyrolysis plant would provide a source of heat to dry the grains for sale and could also use grains as a feedstock.

1.1.4 Paper Waste

NYS has the most paper mills of any state (Fagan 2007). In 2004, 24 of 37 mills used recycled materials. However, approximately 0.144 million dry tons of waste are produced by these facilities yearly. Solvay Paperboard in Syracuse, N.Y., represents the largest user of recycled materials; yet produces a waste stream of approximately 52,000 tons per year that they pay to dispose of. This amount is sufficient to maintain a pyrolysis facility.

1.1.4.1 Case Study 5: Solvay Paper Board - segregates solid waste stream with alternate disposal routes

Disposal of solid waste is an issue for paper mills, both in terms of options and cost. Most pay tipping and hauling fees to dispose of their solid waste. Solvay Paperboard is the second largest, single-site facility for secondary fiber consumption in the United States. Solvay segregates their solid waste into three fractions prior to disposal. (Many mills operate as such that they have a single stream of solid waste.) The segregation is:

- Tails - co-mingled heavy plastic and metal wire
- Plastics - mostly polystyrene and polyethylene, with some wet fiber
- Fiber - mostly wet fiber with some sand and grit.

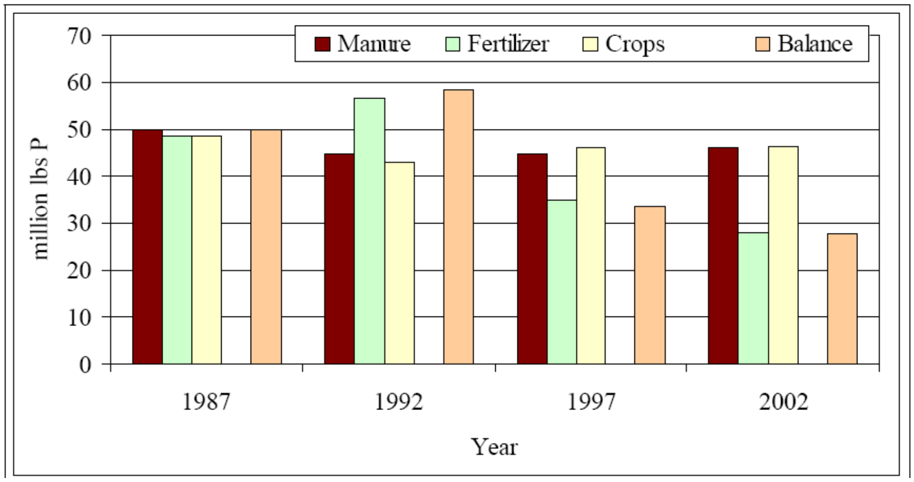
Both the tails and plastics are sent to a landfill. The fiber is sent to Syracuse Fiber, which makes animal bedding from the fiber. The tipping fee charged by Syracuse Fiber is much lower than that charged by the landfill.

1.1.5 Dairy Waste

Nutrient applications from fertilizers and animal manures are essential to crop production, however, when applied in excess, they can become sources of ground and surface water pollution. Dairy and livestock enterprises are of particular concern; typically more nutrients come onto these farms (i.e., feedstocks, fertilizer) than leave as products. For the year 2002, there was a net gain of 28 million pounds of phosphorus in NYS due to application of fertilizer (17 pounds of P_2O_5 per harvested acre). Unfortunately, despite the volume of available phosphorus in manure, approximately 30 million pounds are imported to the State annually (Figure 2).

Figure 2: Phosphorus balance for NYS in 1987, 1992, 1997 and 2002.

Source: http://nmsp.css.cornell.edu/publications/articles/extension/Pbalance2006.pdf)



Pyrolysis offers a strategy to process manure, potentially facilitating the use of manure-derived phosphorus in NYS. In brief, manure solids can be separated from the bulk manure liquid, dried, blended with other feedstocks, and used as feedstock for pyrolysis. The biochar produced by the process can then be used to recover nutrients from the remaining liquid slurry, which would produce a densified, nutrient-rich fertilizer product that is stable and easily stored or distributed. Initial testing of such products has shown considerable agronomic advantage from application of phosphorus-laden biochar. Manure management is a significant burden to NYS dairy farmers; it's been estimated that they would pay a fee on the order of \$0.015 per gallon (\$0.004 per liter) for off-site manure treatment.

Locating a pyrolysis facility in close proximity to a large concentrated animal feeding operation (CAFO) dairy or in a central location serving several smaller farms was assessed in this project. Approximately 150 large CAFO dairies exist in NYS (average herd size of approximately 1,000 cows). Additionally, there are 473 medium CAFOs (average herd sizes of approximately 500 cows). A typical lactating cow can produce up to 150 pounds of manure a day, depending on nutrition, milk production, and other factors, whereas other estimates range from 20 to 80 pounds per day. These estimates mean one cow can produce between 7,300 and 54,750 pounds of manure per year (or 869 to 6518 gallons). These numbers are for dairies with freestall barns (Gooch 2007).

The size of a herd is often limited by the size of the farm's land base. CAFOs and dairy farms in general, must have sufficient land base on which manure can be spread. CAFOs are required to have a yearly Certified Nutrient Management Plan developed, which costs $10-15/acre. The plan gauges the nutrient loading capacity of the land and regulates how manure can be spread upon it. Manure storage is usually necessary to maintain compliance with the plant. With storage, issues associated with odor complaints and increased pathogenicity become more prevalent.

The desire to reduce odors, reclaim bedding solids from the manure stream (bedding can cost up to $100 per cow per year), and reduce the volume of manure requiring storage, has resulted in installations of anaerobic digester at numerous NYS dairies. In addition to the previously mentioned benefits, the farm benefits from on-farm energy production through the combustion of biogas produced in the digester (Gooch et al. 2005a). However, it should be noted that operating an anaerobic digester is a significant undertaking.

In most cases raw manure is fed directly to the digester, where it may be mixed with additional waste inputs (e.g., food plant processing wastes). The addition of food waste has proven to be highly profitable (Wright and Ma 2003), but can only be accepted by farms with the land base to support the additional nutrients associated with the food wastes. Food wastes are typically high in energy content, and may greatly increase digester gas production per unit mass of manure. However, solids recovery (i.e., bedding) is decreased due to stimulated microbial productivity (Wright and Ma 2003).

From the digester, the effluent is typically pumped to a screw-press (or other comparable technology), where the liquid fraction is separated from the solid fraction. The liquid fraction is pumped to long-term storage, and land applied on an as-needed basis. Compared to stored raw manure, this liquid fraction has a significantly lower pathogen concentration and is less odiferous.

As a rule, the majority of nutrients follow the liquid fraction; 80 percent of the nutrient load is contained in the liquid fraction after separation. The solid fraction does, however, remain relatively wet, with a moisture content of 70 to 80 percent and total solids of approximately 23.7 to 29.3 percent (Gooch et al. 2005b). This solid fraction is then typically dried in a rotary drum composting system, and either used as stall bedding or blended with other farm wastes and composted. Some farms sell the compost; however, most accumulate the biomass in large, on-site piles.

1.1.6 Poultry Waste

The poultry industry in NYS is a robust agribusiness focusing largely on egg-laying hens and broiler production. In September 2007, the United States Department of Agriculture – Agricultural Marketing Services (USDA-AMS) Poultry Program identified 525 farms with 4.2 million egg-laying hens and 421 farms with 3 million broilers in

NYS. Slow pyrolysis is well-suited to the processing of poultry manure; however, preliminary analysis shows that selling poultry manure requires less investment than a pyrolysis system would. Therefore, it seems that opportunities in NYS are only likely to arise where there is a specific constraint to a poultry business.

1.1.6.1 Case Study 6: Kreher's Farm – produces compost and other high value products

Kreher's Farm (Erie, N.Y.) is the third largest egg laying operation in NYS with 550,000 laying hens. The farm generates approximately 8,000 tons of manure per year, which is free of bedding material. The manure is composed of 20 percent mineral matter and has a 50 percent moisture content. Kreher's began composting their manure in 1994. Composting is performed indoors and nothing is added to the manure. The farm produces about 6,000 tons of finished product annually, which is sold as fertilizer at $60 per ton to local organic farmers. The farm also applies some of the compost on their 3,000 acres (1214 hectares) of organic crops. Finally, about 2,500 tons of the compost is run through a pellet mill to create a higher value product for sale as fertilizer (Wright and Graf 2004). Based on a financial analysis of Kreher's facility, the income derived from composting represents approximately $3.75 per wet ton of waste.

1.1.7 Estimating Available Feedstocks in NYS

A questionnaire was developed to determine the actual amount and availability of feedstocks within the 62 counties of NYS. NYS census data was also reviewed and the average amount of waste generated per household quantified based on national averages. Additionally, based on the estimated number of households, an estimate of potential volume of residential yard waste was developed. Early on in the process, it became obvious that these feedstock streams are typically not well documented. The following is a summary of the information gleaned from the analysis of two counties, Oswego and Tompkins.

1.1.7.1 Oswego County

Yardwaste/Woodchips. Now that the Bristol Hill Landfill charges tipping fees for residential leaf and yard waste, the cities of Fulton and Oswego no longer truck these wastes to the landfill.

The City of Oswego Department of Public Works collects residential yard waste. City officials estimate that approximately 2,000 tons/year are collected. The city accumulates the yard waste and wood chips from storm debris/tree removal on a city-owned lot. The chips are periodically offered to city residents free of charge.

Food waste. Due to odor complaints and lack of accessible bulking agents (paper mill pulp and wood chips), the county no longer accepts food waste and fish entrails at its Bristol Hill composting facility. These wastes are now sent directly to the Bristol Hill Landfill.

Birds Eye sends its food processing waste to Toad Hollow, a commercial composting operation in Onondaga County.

SUNY Oswego, area hospitals and restaurants do not source separate food waste for composting.

Manure.All farms in the county fall under the small to medium categories (60 or less animals) with the exception of a large bull operation, which is installing a manure storage facility. All manure is land applied on farm property within the county. Manure from Plainville Turkey Farm (Onondaga County) and a large CAFO (Jefferson County) is also land applied in the county.

1.1.7.2 Tompkins County (Does not include Cornell University, which is treated as a separate case study.)

Yardwaste/Woodchips. In the spring of 2008, the City of Ithaca collected 230.88 tons bagged leaf and other yard waste (Source: Dan Spencer, Head of Sanitation), which was subsequently taken to Cayuga Compost. There is no information on the volume of biomass collected (and taken to Cayuga Compost) in the fall.

A large woodchip pile is maintained in the City of Ithaca. According to the city's forester, Andrew Hillman, residents can take two garbage cans a day for free, and Cascadilla Tree is allowed to deposit chips at the site for free.

The Town of Ithaca maintains a site where Cascadilla Tree is allowed to deposit woodchips for free; Town residents are subsequently allowed to take them for free. Brush and logs are ground in a tub grinder, which creates a very fine, fast decomposing material.

The Town of Lansing also maintains a woodchip pile. Cayuga Heights pays a tipping fee to the town to take their brush.

According to Drew Lewis at Cayuga Compost, in 2008, Cayuga Compost produced approximately 2,500 cu yd of finished product from 1,850 tons waste. The product is a high quality, dry product that was sold for $40/cu yd. Wood chips are used for aeration in the compost piles. At finishing, screens are used to remove the wood chips, which are then re-used (see Case Study 3).

Cascadilla Tree owner John Friederborn employs 6 to 8 full time staff. The company generates more waste and marketable flows than all other arborists in the county combined, including1,200 - 1400 cu yds/year sold to Sapsucker Woods (sold below wholesale). Approximately 2,500 cu yd/year sold at retail. (If not sold, it is deposited at either the City's pile or the Town's pile, dependent upon the distance.)

Cascadilla's yard currently holds 16,000 - 17000 cu yds of tub ground "weed trees" (poplar, spruce, silver maple, boxelder). Once per year a tub grinder is rented (at $450/ hour; $4000/day with labor) to process the trees. The amount generated varies yearly, but the produce is not marketable as it decomposes quickly and is not a desirable color.

Food waste. Tompkins County has a pilot program with Cayuga Compost. The county subsidizes half of the costs of food waste composting for businesses involved in the program. (Without the subsidy, it is less expensive for businesses and school to send their food waste to the landfill.) The hope is that as more businesses source separate their food wastes and subsequently send them for composting, the costs will decrease.

1.2 Markets for Biochar

Whereas biochar may have a widespread benefit in terms of carbon sequestration and improved fertilizer use efficiency in row crops, it is unlikely that row crops such as corn represent the initial market for biochar. The margins on such crops are small and the current economic situation favors application of nitrogen fertilizer to maximize production. Adoption of biochar would require a difficult proposition, investing in soil quality to realize future savings in fertilizer.

Therefore, this study identified potential high value markets within NYS where biochar was likely to be an acceptable product and the business model was perceived as being open to new innovations and investments in soil quality. The markets identified were those associated with turfgrass applications, wetland restoration and high value vegetable and orchard situations. These markets are briefly assessed as follows.

1.2.1 Turfgrass Applications

A survey of NYS's turfgrass sector was performed in 2003, and was a key source of market data for this study. Table 3 indicates a total of 3.43 million turf acres (1.38 million hectares) were reported. Private residences, lawn care and golf courses account for 93 percent of the total acreage. A total of 843,323 new turf acres in NYS were established in 2003 at a cost of nearly $1.56 billion.

A recommended practice for establishing turfgrass can be found at http://turfgrassmanagement.psu.edu/homelawns.cfm. In brief, soil is rough-graded before the addition of lime and basic fertilization. Organic matter is then added, the soil tilled, and a starter fertilizer applied. There are three potential applications for biochar in the turfgrass sector:

- The first is as a constituent of the rootzone mix used when establishing turfgrass.
- The second is a topdressing product used once the turfgrass has been established.
- The third is a controlled release fertilizer product.

Table 4 shows the expenses associated with turfgrass maintenance. The average annual expenditure for supplies associated with turfgrass maintenance for parks, private residences and lawn care service companies are $156, $196 and $274 per acre, respectively. The following sections examine how biochar may be positioned in each of the markets identified.

1.2.1.1 Rootzone mix

Turfgrass is traditionally established using a mix of sand, topsoil and organic matter. Peat and compost are typically used as the organic matter sources in such mixes. In high value situations, such as golf courses or athletic fields, inert products are used for both construction and topdressing purposes. Two of the leading products (PROFILE™ and ZeoPro™) are described as follows.

Golf course greens are typically constructed with a rootzone mix that is predominantly made up of sand. Traditionally, the sand is mixed with peat or compost during construction. Peat helps the soil to retain nutrients and improves soil moisture retention. The key advantage of using peat is its cost ($2.25-$9.00/cu yd); however, peat breaks down over time and is affected by compaction (Nelson 2003). Two alternative products, zeolites or non-porous ceramics, are used as substitutes for peat.

Based on the U. S. Golf Association guidelines, construction of a typical 18-hole course requires about 7,000 cu/yd of rootzone mix or approximately 7,000 tons. Where peat is used as a substrate, no compensation is made for the volume of the peat. However, for the inorganic products the amount of sand used is reduced and the products are substituted on a 1:1 weight basis.

Biochar would displace the sand fraction. A golf course constructed with a 15 percent biochar rootzone mix would require 1,050 cu yd biochar. Sand has a density of 250 kilograms per cubic meter. Because biochar is considerably less dense than sand, a 15 percent biochar rootzone mix equates to 221 tons of biochar per course.

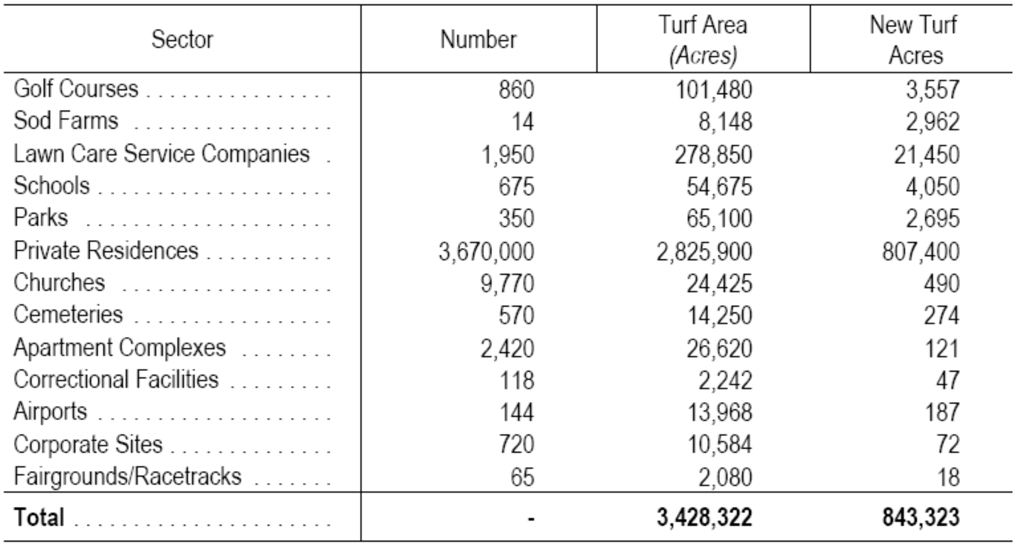
The cost of rootzone mix depends on trucking fees and local availability of sand. The cost per ton might be as low as $15, but could also be as high as $45. The value of the sand displaced by a ton of biochar is between $71 and $214 per ton. The competing products, PROFILE and ZeoPro™, are both more dense than biochar, and are recommended for use at a 15 percent weight basis in rootzone construction with a 1:1 substitution for sand. Thus, having corrected for the difference in density, the value for biochar is $1,225 per ton.

The competitive price of biochar is likely to be affected both by the cost of sand (which it displaces in rootzone construction) and by the competing inorganic products. The potential price range then falls within the range of $70 – $1,225 per ton.

Preliminary estimates conducted for this report indicate that the retail price for biochar in this market would be greater than $400 per ton, which would give it a considerable price advantage over the competing inorganic products.

Table 3: Turfgrass area and new turf areas established in 2003.

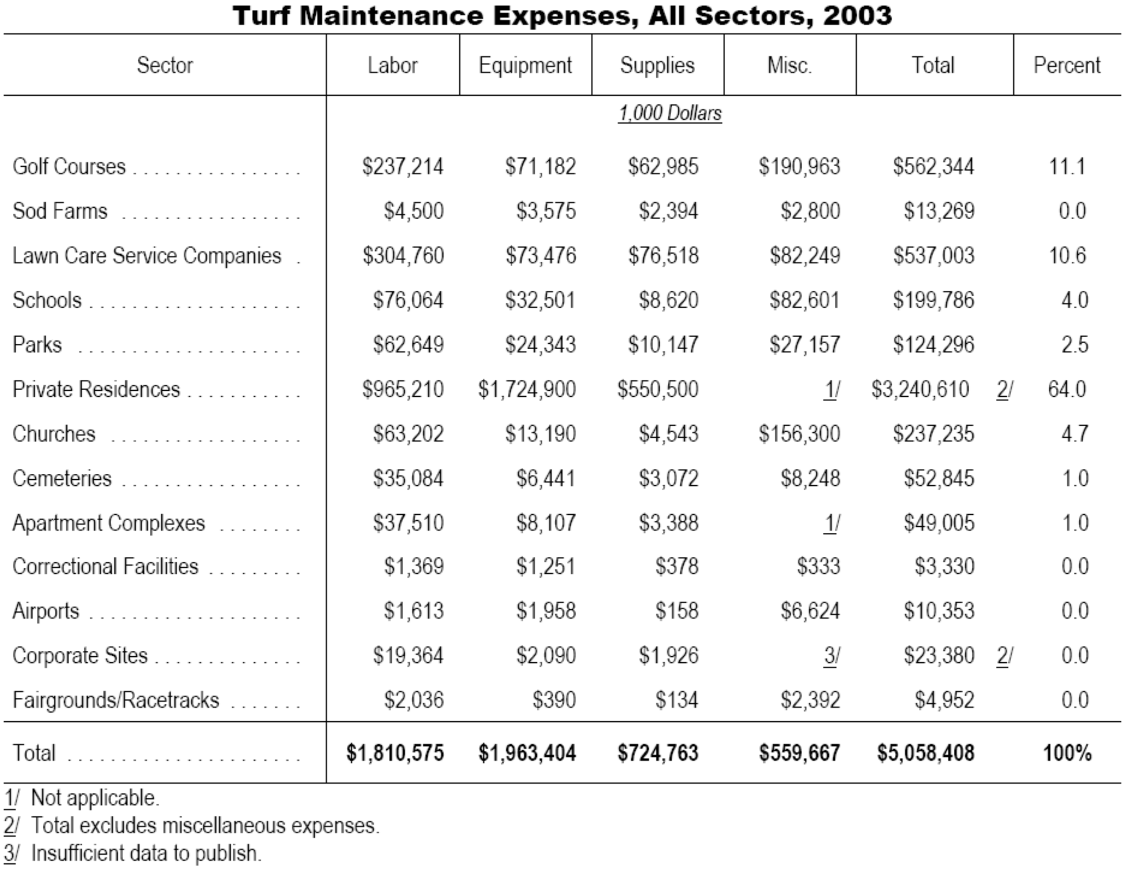
Source: NY Turfgrass Survey, NASS, 2004.



Sector	Number	Turf Area *(Acres)*	New Turf Acres
Golf Courses	860	101,480	3,557
Sod Farms	14	8,148	2,962
Lawn Care Service Companies .	1,950	278,850	21,450
Schools	675	54,675	4,050
Parks	350	65,100	2,695
Private Residences	3,670,000	2,825,900	807,400
Churches	9,770	24,425	490
Cemeteries	570	14,250	274
Apartment Complexes	2,420	26,620	121
Correctional Facilities	118	2,242	47
Airports	144	13,968	187
Corporate Sites	720	10,584	72
Fairgrounds/Racetracks	65	2,080	18
Total	**-**	**3,428,322**	**843,323**

Table 4: Turfgrass maintenance costs for New York State.

Source: NY Turfgrass Survey, NASS, 2004.



Turf Maintenance Expenses, All Sectors, 2003

Sector	Labor	Equipment	Supplies	Misc.	Total		Percent
			1,000 Dollars				
Golf Courses	$237,214	$71,182	$62,985	$190,963	$562,344		11.1
Sod Farms	$4,500	$3,575	$2,394	$2,800	$13,269		0.0
Lawn Care Service Companies	$304,760	$73,476	$76,518	$82,249	$537,003		10.6
Schools	$76,064	$32,501	$8,620	$82,601	$199,786		4.0
Parks	$62,649	$24,343	$10,147	$27,157	$124,296		2.5
Private Residences	$965,210	$1,724,900	$550,500	1/	$3,240,610	2/	64.0
Churches	$63,202	$13,190	$4,543	$156,300	$237,235		4.7
Cemeteries	$35,084	$6,441	$3,072	$8,248	$52,845		1.0
Apartment Complexes	$37,510	$8,107	$3,388	1/	$49,005		1.0
Correctional Facilities	$1,369	$1,251	$378	$333	$3,330		0.0
Airports	$1,613	$1,958	$158	$6,624	$10,353		0.0
Corporate Sites	$19,364	$2,090	$1,926	3/	$23,380	2/	0.0
Fairgrounds/Racetracks	$2,036	$390	$134	$2,392	$4,952		0.0
Total	**$1,810,575**	**$1,963,404**	**$724,763**	**$559,667**	**$5,058,408**		**100%**

1/ Not applicable.
2/ Total excludes miscellaneous expenses.
3/ Insufficient data to publish.

Where biochar is applied, liming rates associated with establishing turfgrass can be reduced by an estimated one-third, and that basic fertilization can be avoided. The costs associated with peat or compost are also eliminated, and we assume that fertilization prior to seeding is cut by 50 percent. Assuming these savings can be transferred to the value-added biochar product, the price becomes $44 per cu/yd, which is equivalent to approximately $211 per ton. Table 5 summarizes the costs for turfgrass application for an area of 1000 square feet (92.9 square meters).

Biochar also reduces the ongoing fertilizer costs over the life of the lawn, but it is not clear how much of this value can be added to the product. However, assuming 50 percent of the value can be captured, the value for biochar is $65 per cu yd or $310 per ton.

Table 5: Rates and costs for establishing turfgrass ($ per 1000 sq ft).

Source: http://turfgrassmanagement.psu.edu/

Product				Conventional		Biochar	
	Cost	Source	unit cost	rate	cost	Rate	Cost
Lime	$7.49/50lb bag		0.15 lb	100	$14.98	66	9.89
Compost	$40/cu yd		40.00 cu yd	6.2	$248.00	0	0.00
Basic Fertilizer 0-44-0	$4.99/ 5lbs		1.00 lb	35	$34.93	0	0.00
Fertilization prior to seeding	$39.99/ 15 lb		2.67 lb	3	$8.00	1.5	4.00
Seed	$8.99/ 3lbs		3.00 lb	5	$14.98	4.5	13.49
sub-total					**$320.89**		**46.06**
Biochar			44.33 cu yd	0	$0.00	6.2	274.83
Total					**$320.89**		**$320.89**

1.2.1.2 *Topdressing and fall fertilization*

Under conventional turfgrass management, fertilization and topdressing with organic matter are separate operations. The recommended annual application rate for organic matter (compost) is 1 cubic yard per 1,000 square feet. Assuming $40 per cubic yard for compost and $5.60 per 1,000 square feet for fall fertilizer (http://www.grenviewfertiliser.com), the cost would be $46 per 1,000 sq ft.

The assumption is that biochar would also be applied annually at a rate of 1 cubic yard per 1,000 square feet. If similar pricing is assumed, the biochar would have a value of $220 per ton. However, as previously described, a premium could potentially be added based on the benefits of biochar. At a premium of $15 per cubic yard, this price brings the value of the biochar to $291 per ton.

1.2.1.3 *Controlled-release fertilizer formulation*

Because competing products cost $4 per 1,000 square feet, it is not clear that biochar would position well. The benefits in nutrient conservation are achieved through using biochar in grass establishment and topdressing, which delivers both nutrient saving and environmental benefits.

1.2.2 Wetland Restoration

NYS has an estimated 2.4 million acres of wetlands. The most saturated ecoregions are the Lake Plains and the Adirondacks; together they encompass 74 percent of the State's wetlands. The most common wetland cover-type is forested (70 percent), followed by shrub/scrub (16 percent), emergent (9 percent) and wetland open water (5 percent). Typically, the NYS Department of Environmental Conservation installs about 5,000-10,000 acres per year, including riparian buffers, and Partners for Wildlife, which is part of the U.S. Fish and Wildlife Service, installs about 500-1,000 acres per year, which does not include buffer zone acreage.

The cost of wetland construction varies greatly depending on whether restoration, creation, or mitigation is being performed. Mitigation efforts tend to be the most costly (in the range of $50,000 to 180,000 per acre). The specific costs associated with the mitigation of a 4.4 acre forested wetland site in Upstate New York includes $90,000 for construction costs and $60,000 for planting and seeding. Assuming that half of the 1,000 trees required will be low-cost and the other half will be higher-priced Root Production Method trees, an additional $337,500 must be added to the overall cost of the project. Therefore, the rough estimate for construction and planting of a 4.4 acre mitigated upstate NY forested wetland site is $487,500 (or $110,775 per acre). Note that this estimate does not include the cost of the land or fees associated with the required five-year monitoring period.

If biochar were incorporated into the process, it would likely be applied after the topsoil was removed, but prior to planting. The addition of biochar to the process should facilitate growth of the planted trees, which is one of the main criteria for successful remediation of forested wetlands. It is currently assumed that biochar should be added to such systems at a rate of 25 tons per acre. Assuming biochar costs $100 - $300 per ton, application of biochar to the project would add $2,500 - $7,500 to the total costs, which is a fairly insignificant addition to the overall budget. The added costs could be rationalized as the biochar facilitating tree growth. If NYS DEC were to adopt use of biochar for wetland mitigation, it would open a potential market of 125,000 – 250,000 tons of biochar per year.

1.2.3 High-Value Agriculture

According to U.S. Department of Agriculture census data, high-value vegetable and orchard crops were grown on 143,967 acres of land in NYS in 2002 . Table 6 summarizes the typical fertilizer rates and costs for a range of crops. Based on the information presented in the table, the application ofapplying biochar to soil results in crops with a reduced need for lime, fertilizer and irrigation. In addition, less seed is needed with biochar than when conventional techniques are used. Assuming these benefits would last over a 10-year period, the cost savings range from $400 to $1,600 per acre over a ten-year period.

Table 6: Summary of the projected benefit due to application of biochar to high value crops ($ per acre).

Product				Conventional		Biochar	
	Cost	unit cost ($)		rate	cost ($)	Rate	Cost ($)
Sweet corn							
Lime (incl hauling and spreading)	$40/ton	40.00	ton	0.5	$ 20.00	0.33	$ 13.20
34-0-0	$1.15/lb	1.15	lb	220	$ 253.00	176	$ 202.40
12-51-0	$1.3/lb	1.30	lb	198	$ 257.40	158.4	$ 205.92
0-0-60	$0.88/lb	0.88	lb	220	$ 193.60	176	$ 154.88
Seed	$10/lb	10.00	lb	10	$ 100.00	9	$ 90.00
Irrigation	$50/acre	50.00	acre	1	$ 50.00	0.9	$ 45.00
sub-total					**$ 874.00**		**$ 711.40**
Annual benefit due to biochar application							$ 162.60
Projected benefit over 10 y							**$ 1,626.00**
Onion							
Lime (incl hauling and spreading)	$40/ton	40.00	ton	0.5	$ 20.00	0.33	$ 13.20
Nitrogen	$0.50/poun	0.50	lb	100	$ 50.00	80	$ 40.00
Phosphorous	$0.28/poun	0.28	lb	80	$ 22.40	64	$ 17.92
Potassium	$0.15/poun	0.15	lb	80	$ 12.00	40	$ 6.00
Nitrogen (postsidedress)	$0.50/poun	0.50	lb	80	$ 40.00	72	$ 36.00
seeds	$500/acre	500.00	acre	1	$ 500.00	1	$ 500.00
Irrigation	$800/acre	800.00	acre	1	$ 800.00	0.9	$ 720.00
sub-total					**$ 1,444.40**		**$ 1,333.12**
Annual benefit due to biochar application							$ 111.28
Projected benefit over 10 y							**$ 1,112.80**
Cabbage							
Urea 46-0-0	$0.49/lb	0.49	lb	180	$ 88.20	118.8	$ 58.21
Phosphorous 0-46-0	$0.43/lb	0.43	lb	40	$ 17.20	32	$ 13.76
Potassium 0-0-60	$0.23/lb	0.23	lb	180	$ 41.40	144	$ 33.12
Transplants	$111/thous	111.00	thou	16	$ 1,776.00	16	$ 1,776.00
Irrigation					$ -	0	$ -
sub-total					**$ 1,922.80**		**$ 1,881.09**
Annual benefit due to biochar application							$ 41.71
Projected benefit over 10 y							**$ 417.08**
Potato							
Lime(incl hauling and spreading)	$40/ton	40.00	ton	0.5	$ 20.00	0.33	$ 13.20
Nitrogen	$0.27/lb	0.27	lb	200	$ 54.00	160	$ 43.20
Phosphorous	$0.28/lb	0.28	lb	150	$ 42.00	120	$ 33.60
Potassium	$0.15/lb	0.15	lb	150	$ 22.50	120	$ 18.00
Seed	$12.50/cwt	12.50	cwt	20	$ 250.00	18	$ 225.00
Irrigation						0	
sub-total					**$ 388.50**		**$ 333.00**
Annual benefit due to biochar application							$ 55.50
Projected benefit over 10 y							**$ 555.00**
Orchard establishment							
Lime	$75/acre	75.00	acre	1	$ 75.00	0.66	$ 49.50
Fertilizer	$64.25/acr	64.25	acre	1	$ 64.25	0.50	$ 32.13
Grass seed	$45/acre	45.00	acre	1	$ 45.00	1.00	$ 45.00
Trees	$1,904/acr	1904.00	acre	1	$ 1,904.00	1.00	$ 1,904.00
sub-total					**$ 2,088.25**		**$ 2,030.63**
Annual benefit due to biochar application							$ 57.63
Projected benefit over 10 y							**$ 576.25**

1.2.4 Carbon Sequestration Potential Related to Applying Biochar

Based on application in the turfgrass, wetland restoration and high-value vegetable and orchard markets, biochar represents an estimated total sequestration potential in NYS of 116.6 million metric ton carbon equivalents (MMtCE) (Table 7). Field crops acreage estimates are based on information from the U.S. Department of Agriculture. In estimating sequestration, potential application to field crop has been included, which is likely not viable at this point in time. For perspective, the total emissions for NYS in 1990 were 75.7MMtCE.

Table 7: Estimated sequestration for carbon sequestration through biochar application (MMtCE).

	Area	Biochar application rate	potential biochar use	Carbon seqestered	Assumed market penetration	potential biochar use	Carbon seqestered
	(acres)	(t / acre)	(t)	(Mt C)		(t)	(Mt C)
Mitigated Wetland	10,000	25	250,000	170,081	90%	225000	153073
Grass establishment	843,223	57	47,886,634	32,578,474	5%	2394332	1628924
Golf course green construction	100	77	7,718	5,251	20%	1544	1050
Topdressing	3,428,322	9	31,403,430	21,364,538	5%	1570171	1068227
Vegetable production	143,967	30	4,319,010	2,938,330	25%	215951	146917
Field and Misc crops	2,917,000	30	87,510,000	59,535,241	10%	4375500	2976762
Total			**171,376,792**	**116,591,916**		**8,782,497**	**5,974,952**

1.2.5 Carbon Trading

As outlined in The Economics of Climate Change: The Stern Review (Stern, 2006):

> Expanding and linking the growing number of emissions trading schemes around the world is a powerful way to promote cost-effective reductions in emissions and to bring forward action in developing countries. Strong targets in rich countries could drive flows amounting to tens of billions of dollars each year to support the transition to low-carbon development paths.

However, how these drivers will translate into a market in the U.S. and NYS is uncertain. At present, the United States has not ratified and does not participate in the Kyoto Protocol Process (United Nations 1998), which represents the most widely recognized market.

NYS is part of the Regional Greenhouse Gas Initiative (RGGI), a cooperative effort of nine Northeast and Mid-Atlantic states. According to RGGI documents (www.rggi.org):

> The program shall start simply and develop over time. The initial phase of the cap-and-trade program will entail the allocation and trading of carbon dioxide allowances to and by sources in the power sector only. In a subsequent phase of the program, states and stakeholders will work together to develop reliable protocols for offsets (i.e., creditable reductions outside the power sector) that may be used to achieve compliance with the cap. States may be able to achieve greater emissions reductions as the number of sources covered and the variety of compliance options increases, thereby reducing compliance costs.

In addition to formal markets for carbon offsets, there is an emerging voluntary "grey market" for these offsets, which is driven both by corporate and social interests to be carbon neutral or negative. This market is extremely difficult to quantify. A key assumption is that qualifying projects will be held to the highest international standard, which is currently to be Kyoto compliant by demonstrating that the emissions reductions generated have been produced and verified to a standard equal of that required of a Kyoto project. Following this framework, potential sources of avoided emissions relevant to the proposed use of pyrolysis and biochar are described in the following section.

1.3 Source of avoided emissions

1.3.1 Using pyrolysis to control emissions from biogenic waste streams

CH_4 emissions are produced from the decomposition of biogenic materials as a result of the man-made anaerobic conditions found in many landfills. In contrast, carbon dioxide (CO_2) emissions produced from the combustion or decomposition of biogenic materials (e.g., paper, wood products, and yard trimmings) grown on a sustainable basis are considered to mimic the closed loop of the natural carbon cycle; that is, they return to the atmosphere CO_2 that was originally removed by photosynthesis. That being said, the use of controlled pyrolysis as a strategy to avoid the CH_4 emissions associated with management of biogenic materials in landfills has been established as a potential small-scale Clean Development Mechanism (Kyoto compliant) project activity. (Approved methodologies for small-scale Clean Development Mechanism project activities and procedures for small-scale clean development mechanism project activities were set out as decision AMS-III.L. [United Nations 2006]. The small-scale methodology addresses the avoidance of methane that would have been produced from residues left to decay under anaerobic conditions. The same principle can be applied to nitrous oxide (N_2O) emissions; however, the avoided emissions need to be established in each specific situation.)

In a scenario where biogenic materials are diverted from landfill, the avoided CH_4 emissions are tradable. The amount of avoided CH_4 depends on a number of factors related to the management of a landfill facility and whether CH_4 is recovered through flaring. The calculated CH_4 emission from landfills without CH_4 recovery is 0.87 metric ton CO_2 / metric ton wet yard waste, and where CH_4 is flared is 0.21 metric ton CO_2 /metric ton wet yard waste. (These numbers are converted from MTCE using a correction factor of 3.67 to correct C to CO_2, based on Exhibit 6-6 of *Solid Waste Management and Greenhouse Gases: A Life-Cycle Assessment of Emissions and Sinks, 3rd edition* (US EPA 2006).

Livestock contribute greenhouse gas emissions to the atmosphere both directly and indirectly. CH_4 and N_2O emissions are released into the atmosphere as a result of the decomposition and nitrification/denitrification of livestock manure and urine. The level of CH_4 and N_2O emissions from managed livestock waste depends on a number of conditions. Storage in ponds, tanks, or pits, such as those that are coupled with liquid/slurry flushing systems, often promote anaerobic conditions (i.e., non-oxygen) where CH_4 is produced. (Whereas solid waste stored in stacks or pits tends to provide aerobic conditions where CH_4 is not produced. N_2O is produced when these wastes are first handled aerobically [i.e., the nitrification process converts ammonia or organic nitrogen to nitrates and nitrites] and subsequently handled anaerobically [i.e., the denitrification process converts nitrates and nitrites to nitrogen gas [N_2] with intermediate production of N_2O and nitric oxide [NO]). N_2O emissions are most likely to occur in aerobic, dry waste handling systems that inadvertently contain anaerobic pockets due to saturation.

The U.S. Department of Agriculture calculated greenhouse gas emissions by state and animal, taking livestock management practices in to account (USDA, 2004). Using the information provided in Tables A-1 and A-14 of the report, an estimate was developed for avoided CO_2 emitted per head of dairy cattle (0.6477 metric tons), for a scenario where livestock waste is managed via controlled pyrolysis.

1.3.2 Fossil fuel substitution

Where a biogenic material is used as a source of energy to produce electricity, an offset for the displaced fossil fuel is generated that is tradable. This offset is in addition to any avoided emissions associated with a change in management of the biogenic waste stream. The 1997-1999 state average CO_2 emission coefficient for electric utilities of 0.361 Mt CO_2 / MWh (Energy Information Administration 2001) was used to determine the avoided CO_2 emissions associated with energy generation using a biogenic fossil-fuel substitute.

1.3.3 Carbon stabilization

In addition to fossil-fuel substitution offset, a slow pyrolysis facility using biogenic materials as the feedstock could potentially qualify for carbon stabilization offsets. Compared to direct and indirect combustion technologies for the production of bioenergy, carbon stabilization as a result of biochar generation could represent an avoided emission. The United Nations Framework Convention on Climate Change methodology for small scale CDM projects considers biochar as biologically inert (with respect to its potential to release CH_4) if the volatile-carbon/fixed-carbon ratio is equal to or lower than 50 percent (United Nations 2006). Based on research performed as part of this project, we believe this standard can be met. However, because evidence shows that biochar stability depends on feedstock type and production conditions (Zimmerman 2010), additional work is needed to validate this assertion.

Note that there is an important distinction between the addition of stabilized carbon to soil and the sequestration that results from the addition of crop residue and adoption of practices, such as minimum tillage. The latter is not currently allowed under the Kyoto Protocol, because the carbon contained in the crop residue is rapidly broken down and released in the form of CO_2. Jenkinson and Ayanabana (1977) suggest that only 10 percent of the carbon in crop residues remained after five years. And the IPCC estimates that 100 percent of the carbon contained in the crop residues will be lost during the 10 year accounting period of a carbon trading project (IPCC 1996).

1.3.4 Effect of biochar application on greenhouse gas emissions from soil

When biochar was applied to land under cereal production , empirical evidence showed the following: ammonium leaching was reduced by more than 60 percent in a greenhouse experiment over a 45-day period (Lehmann et al. 2003a); N_2O evasion was significantly reduced (Rondon et al. 2005; Taghizadeh-Toosi et al. 2011); and crop performance improved (Lehmann et al. 2003a; Rondon et al. 2007; Steiner et al. 2007). However, given the wide range of potential applications and uncertainty, these avoided emissions were not included in the preliminary calculations. Obviously there is a need to establish these values so that the avoided emissions can ultimately be tradable.

1.4 Market Value of Avoided Emissions

In 2008, the market price for a metric ton of CO_2 range from $4 at the (now defunct) Chicago Climate Exchange to $20 for Futures at the European Union Emission Trading Scheme. Ultimately the price should range from approximately $25 - $85, if the social costs of climate change are used as the basis for calculating prices (Stern 2007). Sources familiar with both the voluntary and regulated market have suggested that the long term price for biochar will be approximately $100 per metric ton CO_2.

1.5 Conceptual Models

Use of pyrolysis technology has typically been driven by the need to ameliorate or handle a specific waste stream. However, with an increasing awareness of the potential values of bioenergy and biochar, as well as interests in developing carbon offsets as products, models must be established to assess the feasibility of pyrolysis technology in these contexts.

Typical pyrolysis facilities are often less than one-third the size of a typical incinerator. The relatively small footprint of the technology is also important in terms of public perception, and enables pyrolysis systems to be located closer to sources of feedstocks, which reduces the logistics, transport and handling of the feedstocks.

Inherent difficulties in defining models for pyrolysis technologies include:

- Capital costs tend to be very location specific, and the costs of developing a site can vary widely depending on the existing infrastructure and services in place.
- Material handling requirements for different feedstocks can vary widely, and can significantly add to the cost of a facility.
- If the business addresses a particular problem or need (e.g., a waste-based constraint, produces heat or power), the economics can vary significantly.

Despite these limitations, three models are proposed for locating pyrolysis facilities in NYS (Table 8). Model 1 is predicated on the wide-spread waste disposal issue presented by yard waste. Model 2 is predicated on the fact that institutional facilities (i.e., prisons, hospitals and universities) produce large volumes of multiple waste streams that are amenable to pyrolysis. Model 3 is predicated on the discrepancy that often exists between the size of a dairy herd and available land for spreading the manure generated by the herd. (Note: Model 3 is not an on-farm strategy; it is based on co-locating a pyrolysis facility with another synergistic business (e.g., ethanol plant)). The potential customers and benefits of each model are presented in the table.

Table 8: Proposed models, potential customers and summary of benefits.

Model	Potential Customer	Benefits
1. Yard Waste	County facility operators	Reduced transportation requirements; addresses pressing and costly waste management issue; diverts material from landfills; generates potential carbon offsets and sends a strong environmental message
2. Institutional facility	University, hospitals, prisons	Handles wide range of waste streams; products can be used for landscaping, farming applications; generates potential carbon offsets and sends a strong environmental message
3. Green business park	Co-location with waste producers	Handles wide range of waste streams, potential agricultural wastes; could be used to generate heat and energy; products can be used for landscaping, farming applications; generates potential carbon offsets and sends a strong environmental message

2 Task 3: Feedstock Availability and Biochar Production Conditions

Biochars were produced in an experimental batch reactor developed by BEST Energies, Inc. and operated by Matric Inc. (Figure 3).

Figure 3. This pyrolysis unit was used to produce biochar for this study.

Based on the previous identification of those feedstocks that are most abundant, readily available and most cost competitive, a list of feedstocks for subsequent pyrolysis was developed, which are listed in Table 9. Table 9 also includes the charring parameters followed (i.e., temperature of pyrolysis).

Prior to pyrolyzing, the feedstocks were dried to slightly less than 10 percent moisture content. The moisture content of the samples are listed in Table 10. Moisture content is also useful during life cycle analyses; when calculating the energy requirements prior to pyrolysis. Summer yard waste, food waste and manures were found to have high moisture contents; winter brush waste and wood waste had much lower moisture.

The mass recovery following pyrolysis is detailed in Table 11.

The chemical composition of the biochars is detailed in Table 12. The samples were analyzed for basic characteristics including pH, cation exchange capacity (CEC), total carbon, and exchangeable acidity.

Table 9: Collected feedstocks that were sent to BEST Energies for pyrolysis.

Feedstock	Temperature of Production (degrees Celsius)	Amount of Biochar Produced (kg per sample/temperature)
Wood Waste	500	1
Food Waste	300, 400, 500, 600	1
Paper Mill Waste	300, 400, 500, 600	1
Animal/Dairy Manure – pressed	500	1
Animal/Dairy Manure – composted	500	1
Animal/Dairy Manure – digested	300, 350, 400, 450, 500, 550, 600	1
1:1 mixture of Animal/Dairy Manure – composted: Wood Waste	500	1
Yard Waste - leaves/Fall	500	1
Yard Waste - brush/Winter	500	1
Yard Waste - grass/Summer	500	1

Table 10: Water content of feedstocks at sampling and residual moisture after drying.

Feedstock	Water Content at Time of Sampling (% water of wet weight)	Mass of Feedstock Pyrolyzed (kg with residual moisture)	Residual Moisture (% water of wet weight)
Wood Waste/pallets	47.4	4.8	3.6
Food Waste	71.8	17.6	5.7
Paper Mill Waste	48	13.4	7.5
Raw Dairy Manure (barn floor)	76.4	4.2	2.3
Composted Dairy Manure	67.7	4.3	10
Digested Dairy Manure (screw pressed solid fraction)	79.7	30.1	9.4
1:1 Mixture of Composted Dairy Manure and Wood Waste	27.3	4	9.45
Yard Waste - leaves/Fall	53.7	4.07	4.7
Yard Waste - brush/Winter	33.9	5	2.0
Yard Waste - grass/Summer	81.5	8.9	5.1

Table 11: Mass recovery of biochars pyrolyzed at different temperatures.

Sample	Temperature °C	Charge g	Recovery g	Recovery %
Digested Dairy Manure	300	3471	1292	37.2
Digested Dairy Manure	350	4025	1550	38.5
Digested Dairy Manure	400	4005	1230	30.7
Digested Dairy Manure	450	3004	550	18.3
Digested Dairy Manure	500	4000	985	24.6
Digested Dairy Manure	550	4005	990	24.7
Digested Dairy Manure	600	4010	970	24.2
Food Waste	300	4007	1930	48.2
Food Waste	400	4005	1410	35.2
Food Waste	500	5510	2565	46.6
Food Waste	600	4005	1470	36.7
Paper Waste	300	1800	1210	67.2
Paper Waste	400	3200	1950	60.9
Paper Waste	500	3000	1810	60.3
Paper Waste	600	3000	1890	63.0
Raw Dairy Manure – Barnfloor	500	4090	1280	31.3
Composted Dairy Manure & Wood Waste	500	3810	1650	43.3
Composted Dairy Manure	500	4007	2150	53.7
Wood Waste Pallets	500	4277	1250	29.2
Summer Yard Waste	500	4000	1490	37.2
Fall Yard Waste	500	1963	630	32.0
Fall Yard Waste	500	2040	770	37.8
Winter Yard Waste	500	4307	1150	26.7

Table 12: Chemical composition of the biochars (Enders et al., 2012).

Sample ID	Total Carbon (mg/g)	Carbon: Nitrogen ratios	pH_w	pH_{KCl}	Volatiles - Dry Mass Basis (%)	Fixed Carbon (%)	Ash (%)
Composted Dairy Manure	365	12.9	N/A	N/A	N/A	N/A	N/A
Composted Dairy Manure 500 °C	377.5	19	10.3	9.7	33.02	16.9	50.09
DD Manure	449.7	27.4	N/A	N/A	N/A	N/A	N/A
DD Manure 300 °C	560.9	21	9.1	8.3	50.48	10.29	39.23
DD Manure 350 °C	577.2	24.2	9.2	8.3	55.62	31.68	12.69
DD Manure 400 °C	637.6	24	9.3	8.6	58.58	26.91	14.5
DD Manure 450 °C	603.8	24.4	10.2	9.3	41.48	40.75	17.77
DD Manure 500 °C	594.3	23	9.9	8.9	42.67	42.59	14.74
DD Manure 550 °C	609.3	28	10	9.2	41.46	40.96	17.28
DD Manure 600 °C	628.1	28	10	9.4	39.43	41.73	18.84
Food Waste	425.7	17.4	N/A	N/A	N/A	N/A	N/A
Food Waste 300 °C	653.2	11	7.9	7.5	45.42	31.28	23.3
Food Waste 400 °C	524.3	14	8.8	8.1	35.72	18.32	45.96
Food Waste 500 °C	366.6	14	9.9	9.5	33.71	13.59	52.7
Food Waste 600 °C	232.3	23	11	10.9	34.48	13.56	51.95
Paper Mill Waste	235.4	196.9	N/A	N/A	N/A	N/A	N/A
Paper Mill Waste 300 °C	211.6	232	8	8.2	50.15	-0.83	50.68
Paper Mill Waste 400 °C	200.1	182	8.4	8.4	44.20	1.23	54.58
Paper Mill Waste 500 °C	191.6	257	9.8	9.5	42.52	.03	57.45
Paper Mill Waste 600 °C	192.2	247	11.7	11.6	41.12	-0.17	59.05
Wood Waste Cornell Pallets	453.6	220.9	N/A	N/A	N/A	N/A	N/A
Wood Waste Cornell Pallets 500 °C	858.6	231	7.9	8	26.91	62.15	10.94
Yard Waste Fall/Leaves	452.7	45.4	N/A	N/A	N/A	N/A	N/A
Yard Waste Fall/Leaves 500 °C	606.9	53.5	9	8.6	40.32	45.19	14.49
Yard waste Summer/Grass	437.8	9.6	N/A	N/A	N/A	N/A	N/A

Table 12 continued

Sample ID	Total Carbon (mg/g)	Carbon: Nitrogen ratios	pH_w	pH_{KCl}	Volatiles - Dry Mass Basis (%)	Fixed Carbon (%)	Ash (%)
Yard waste Summer/Grass 500 °C	534.6	10.8	9.6	9.2	38.45	59.79	25.46
Yard waste Winter/Brush			N/A	N/A	N/A	N/A	N/A
Yard waste Winter/Brush 500 °C	839.8	609.5	8.4	8.6	40.07	58.17	1.76
1:1 Mix Composted Dairy Manure: Wood Waste	N/A	N/A	N/A	N/A	N/A	N/A	N/A
1:1 Mix Composted Dairy Manure: Wood Waste 500 °C	740.4	116.3	9.8	9.7	25.72	15.76	58.52
Raw Dairy Manure (Barn Floor)	421.3	14.3	N/A	N/A	N/A	N/A	N/A
Raw Dairy Manure (Barn Floor) 500 °C	512.2	24	10.7	10.3	32.99	35.02	31.99

The biochars were analyzed for both effective and potential CEC. Certain method modifications were required in order to perform CEC analyses, due to the inherently different physical characteristics of biochars compared to soils. First, biochars have much greater surface area per unit mass than other materials; hydrophobicity and large internal surface areas can result in slow wetting and slower exchange processes. Second, biochar float may occur in the extraction vessels. Therefore, the following modifications were used:

A double extraction method, using buffered NH_4OAC, was used for base cations (sodium[Na], potassium [K], magnesium [Mg] and calcium [Ca]). This procedure differs from standard soil methodologies that recommend single extraction. A double extraction, using 2 N KCl, was also used to determine the potential CEC. This modification addresses the large surface areas and internal surfaces found in biochars.

After addition of the first volume of NH_4OAC, samples were placed on a shaker for 24 hours. This modification addresses the need for a prolonged wetting period to overcome the hydrophobicity effects.

Finally, prior to extraction, all biochars were uniformly sieved to a size range between 0.5 and 2 millimeters.

Results show large differences in potential CEC as well as exchangeable cations depending on feedstock and pyrolysis temperature. The paper sludge biochar exhibited a large exchangeable Ca concentration, but very low K and Mg concentrations, which is a contrast to manures and biomass biochars. Significant seasonal differences were observed in the K concentration of yard waste biochar; yard waste collected in summer exhibited large concentrations, whereas yard waste collected in the winter exhibited almost none. Potential CEC was greatest in manures and lowest in food waste and paper sludge biochars. The high amounts of potential CEC in manures should be further examined to exclude the possible effects of high ammonium concentrations, as potential CEC is determined by the adsorption potential of ammonium.

Table 13: Exchangeable cations and potential cation exchange capacity of biochars.

Feedstock	Temp °C	Ca (mmol$_c$/kg)	K (mmol/kg)	Na (mmol$_c$/kg)	Mg (mmol$_c$/kg)	Potential CEC (mmol$_c$/kg)
Digested Dairy Manure	300	449.5	303.2	148.4	316.5	443.8
Digested Dairy Manure	350	422.0	294.8	145.7	310.4	456.7
Digested Dairy Manure	400	393.0	309.9	150.8	251.7	297.4
Digested Dairy Manure	450	398.0	337.8	160.2	261.3	336.1
Digested Dairy Manure	500	452.5	329.9	157.6	324.5	478.1
Digested Dairy Manure	550	314.0	342.2	157.2	222.5	279.9
Digested Dairy Manure	600	290.8	412.9	256.7	164.0	151.0
Food Waste	300	57.0	306.5	254.9	26.9	103.9
Food Waste	400	157.4	560.0	412.6	31.8	98.2
Food Waste	500	229.1	387.7	328.1	37.3	88.2
Food Waste	600	568.6	110.5	97.9	266.4	34.4
Paper Waste	300	1046.2	0.17	5.71	16.9	83.1
Paper Waste	400	1209.5	5.09	8.66	22.1	61.6
Paper Waste	500	904.7	1.14	5.50	18.6	29.4
Paper Waste	600	989.8	-1.12	2.83	20.2	34.2
Raw Dairy Manure - Barnfloor	500	359.6	1038.2	399.5	302.5	319.1
Composted Dairy Manure & Wood Waste	500	346.3	76.4	23.5	83.6	102.5
Composted Dairy Manure	500	696.2	205.8	64.5	210.4	166.5
Wood Waste Pallets	500	42.8	4.93	2.82	3.9	288.4
Summer Yard Waste	500	290.1	1136.9	21.0	170.8	273.1
Fall Yard Waste	500	750.0	139.0	27.1	26.2	220.0
Winter Yard Waste	500	72.4	6.30	0.958	0.934	282.7

In addition to chemical properties, biological properties were assessed to discern the 1) differing decomposition rates of biochars produced from varied agricultural byproducts and green wastes; and 2) varying decomposition rates among biochars produced from the same original biomass, but with biochar completion being set at different temperature endpoints.

The hypotheses were:

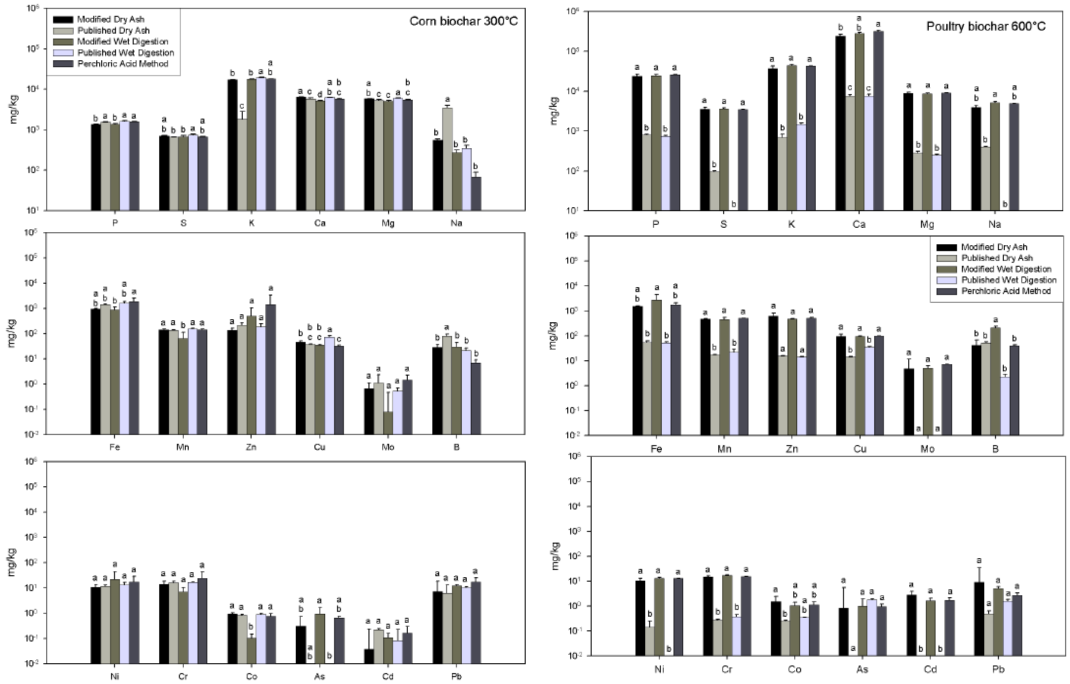
- Different biomass sources would lead to biochars with higher or lower level of recalcitrance when made susceptible to microbial degradation, which would be assessed by measuring the concentration of carbon retained in the system after designated incubation times.
- Varied temperature endpoints for the completion of the charring process would lead to biochars with a higher or lower level of recalcitrance, which would be assessed based on evaluation of chars originating from the same biomass source but having different charring completion temperatures.

The experimental design was as follows:

1. Wheaton glass bottles (30 milliliter [mL]) were filled with four percent carbon by mass and sand (0.8gram [g] carbon to 19.2 g sand).
2. Chars were uniformly sieved to particle sizes between 149 and 850 μm and mixed with sand (50-70 mesh; oven dried at 500 °C for 24 hours).
3. Bottles were filled with three replicates of each of the biochars (each feedstock type at each production temperatures). Bottles were also filled with three replicates of controls, which were the original feedstocks from which the biochars were produced.
4. Microbial inoculum was isolated from a homogeneous mixture of surface and subsurface samples collected at the Cooper Site, Georgia, a historical charcoal furnace where charcoal has “rested” in nearby soils for 130 years. The homogeneous mixture was placed in a 30 °C incubation room for two weeks to stimulate microbial activity. Prior to placement in the incubation room, water was added to the soil to reach 55 percent water holding capacity (WHC). After two weeks, the inoculum was extracted by passing 1 L of de-ionized water through every 25 g of pre-incubated soil.
5. A nutrient/inoculum solution was prepared that consisted of 8 millimolar (mM) $CaCl_2$, 4 mM KH_2PO_4, 2 mM K_2SO_4, 2 mM $MgSO_4$, 50 micromolar (μM) H_3BO_4 , 4μM $MnSO_4$, 4 μM $ZnSO_4$, 1 μM $CuSO_4$, 1 μM Na_2MoO_4, 8 mM NH_3NO_3, 4μM $FeCl_2$. Inoculum was added to the jar so that the volume totaled two liters.
6. A 1.8-mL aliquot of the nutrient/innoculum solution was added to each bottle. An additional 1.55 mL de-ionized water was added to each bottle to reach 55 percent water holding capacity.
7. Jars were left open but placed in a secondary container that contained 5 cubic centimeters (cm^3) de-ionized water to mediate moisture loss within the jars (Baldock and Smernik 2002). The secondary container was loosely closed to protect the jars from contamination and allow for air flow.
8. Each jar’s weight loss was measured on a tri-weekly schedule. Water was then added to the individual jars to bring them back up to 55 percent water holding capacity.

9. Tri-weekly measurements were taken for 6 months, followed by a one-year assessment.
10. Total nutrient analyses were performed to determine: i) the total nutrient inputs to soil; ii) the proportion of available nutrients and subsequent changes with feedstock and production temperature; and iii) the losses of nutrients with pyrolysis temperature. During preliminary experiments, it was found that previously established procedures for digestion of plant matter were inadequate for releasing nutrients from biochars. Therefore, a study was initiated to quantify the errors made when conventional digestion methods were used and to develop modifications to improve digestion for total elemental analyses Figure 4shows that biochar made from high-ash containing poultry manure is insufficiently digested by conventional methods, whereas biochar made from lower-ash containing corn is not, with the exception of Na and a few trace elements (i.e., cobalt, arsenic and cadmium). Given that dry ash methods are more rapid and less expensive, a modified dry ash digestion process was used for subsequent analyses.

Figure 4: Total elemental contents captured by different digestion methods.



2.1 Emissions Monitoring

A sampling system based on the proven design of Lipsky and Robinson (2005) was fabricated to measure the emissions from the pyrolysis process. Figure 5 shows a schematic of the system. Exhaust was sampled isokinetically from a heated inlet line that was maintained at the same temperature as the exhaust to minimize thermophoretic losses. The exhaust sample was then rapidly mixed by turbulence with filtered (HEPA and activated carbon) dilution air inside of a 0.9-m-long, 0.15-m-diameter stainless dilution tunnel. The total flow rate through the dilution sampler was 174 liters per minute, and the dilution ratio was varied by changing the relative amount of exhaust and dilution airflow. Concentrations of CO_2, CO, NO_2, NO, SO_2, O_2 and volatile organic carbon were measured before the exhaust entered the dilution tunnel. Particulate emissions characterization instruments measuring fine particulate matter less than 2.5 µm ($PM_{2.5}$) mass concentrations, particle size distributions and particle filter samples for chemical characterization were connected to sampling ports at the end of the dilution tunnel. The sampler was constructed from stainless steel to minimize contamination.

The system was calibrated with exhaust from the tailpipe of a GMC pickup truck owned by the Sibley School of Mechanical and Aerospace Engineering at Cornell University. But first the exhaust was measured using a Testo 350XL exhaust gas analyzer attached directly to the inlet. In addition, it was measured downstream and post-dilution using the Vaisala Carbocap GMP343 (both for CO_2) as well as downstream for NO and NOx using a 2B Technologies Model 410 Nitric Oxide Monitor and Model 401 NO_2 converter. Assuming no chemical reactions and perfect measurements, the dilution ratio based on carbon dioxide or nitrogen oxides should be the same. The ratios calculated based on the sampling system were 198 and 219, respectively; which was considered to be in good agreement and confirmed that the sampling system was well designed and fabricated. However, the test also revealed that results could be unstable for certain dilution ratios. Therefore, computational fluid dynamics simulations were conducted to improve the dilution tunnel designs. Figure 6 illustrates the computational geometry created for the simulations. And Figure 7 illustrates how the dilution ratios (i.e., dilution air to exhaust air) evolve in the dilution tunnel.

Figure 5: Schematic of the dilution sampling system.

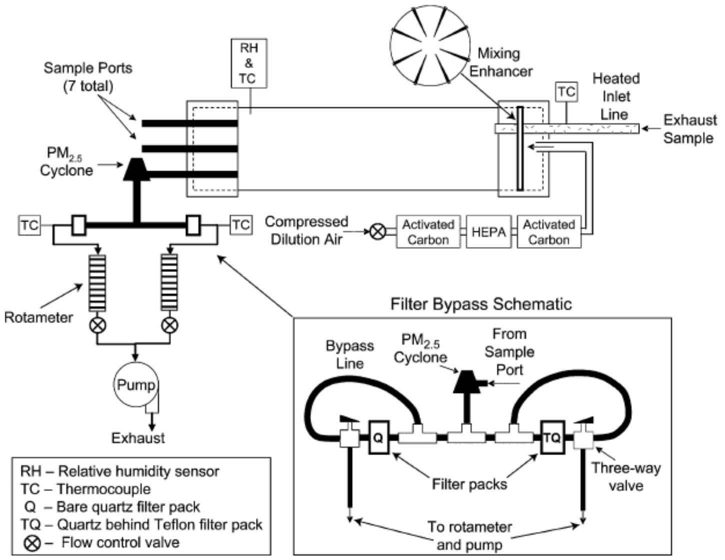


Figure 6: Geometry of the dilution sampling system.

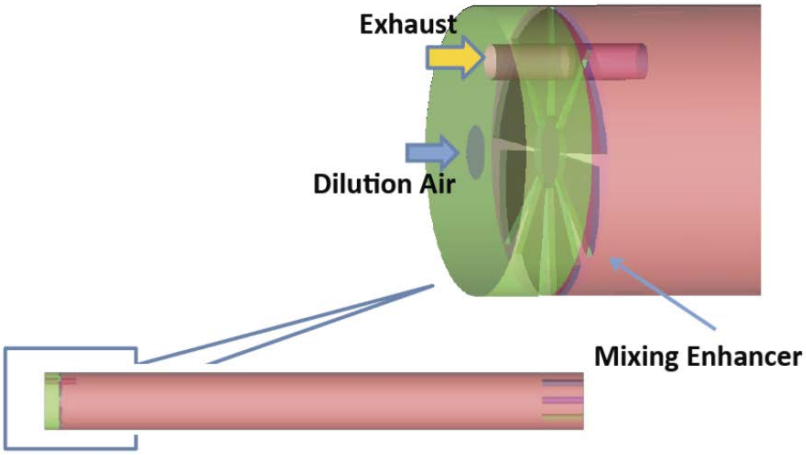
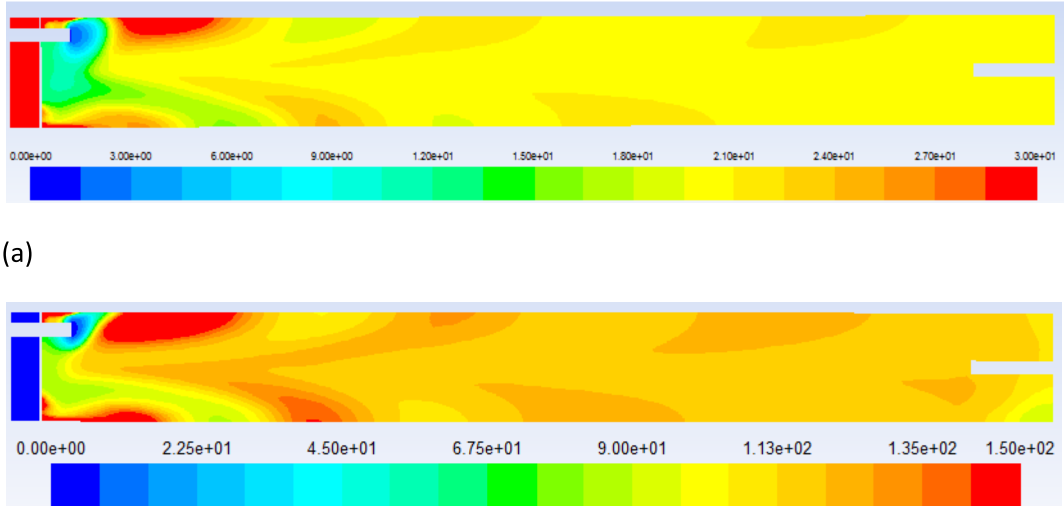


Figure 7: Evolution of dilution ratios for maximum dilution ratio equal to (a) 20 and (b) 120.



(a)

(b)

Based on the simulation results, the design of the sampling system was revised as follows:

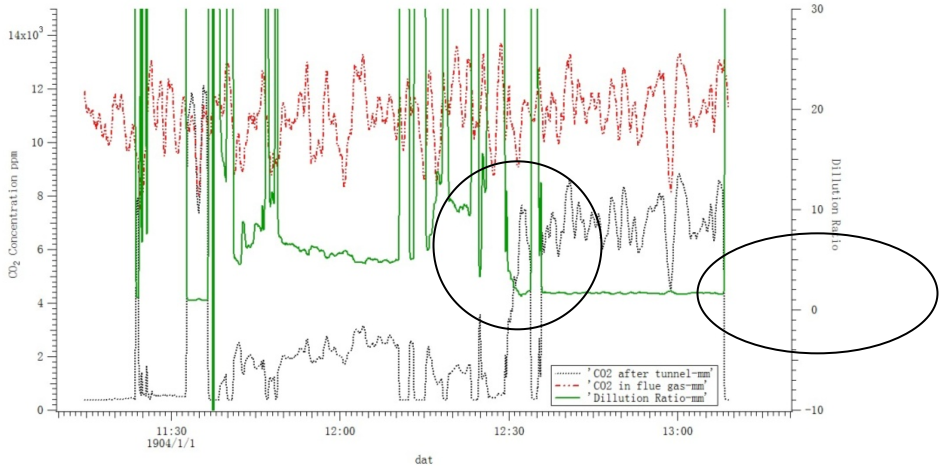
- The stack and exhaust inlet were linked to improve heating so that samples could be collected at an exhaust temperature up to 600K.
- The original pump and flow meters were replaced to achieve more accurate pressure and flow control.

In preparation of the biochar emission tests, the sampling system was used to measure emissions from a wood power burner in King Ferry, N.Y. (Figure 8). The burner operated at high temperature and transient states, similar to an Adam Retort kiln.

Figure 8: Experimental setup for the wood power burner in King Ferry, N.Y.

Figure 9 presents the time series of undiluted and diluted CO_2 concentrations, as well as the dilution ratios derived from the measurements of the King Ferry wood power burner. Although CO_2 concentrations fluctuated over the course of the measurement, the system was able to respond quickly to the changes in concentration so that relatively constant dilution ratios (two encircled regions in Figure 9) were maintained, which is critical to emission characterizations. Unfortunately, emissions measurements from the pyrolysis system could not be collected during the project period.

Figure 9: Time series of undiluted and diluted CO_2 concentrations as well as the dilution ratios derived from the measurements.



3 Task 4: Improving Soil Fertility

Greenhouse trials were performed using biochars obtained under Task 3 to evaluate the potential of biochar application to improve crop productivity and reduce leaching. Soil was gathered from the Cornell Musgrave Research Farm in Aurora, N.Y. True soil was chosen to mimic the biochar/soil interactions that would occur in an amended field setting. The soil was taken from research Field I, a field that represents a continuously cropped corn system, and consisted of Junius loam, Kendaia silt loam, and Lima loam. The pH of the soil was 6.85. The soil was transported to the Guterman Greenhouse complex and air-dried over a series of days. After drying the soil was "shredded" using a Royer Soil Conditioner to eliminate clods. The greenhouse was maintained at recommended corn growing temperatures (i.e., 75°F day, 65°F night). Specialized shelving units were constructed to accommodate the chosen pots for the experiment and to facilitate a coupled leaching experiment (Figures 10 and 11).

Figure 10: Corn plant growth tests.

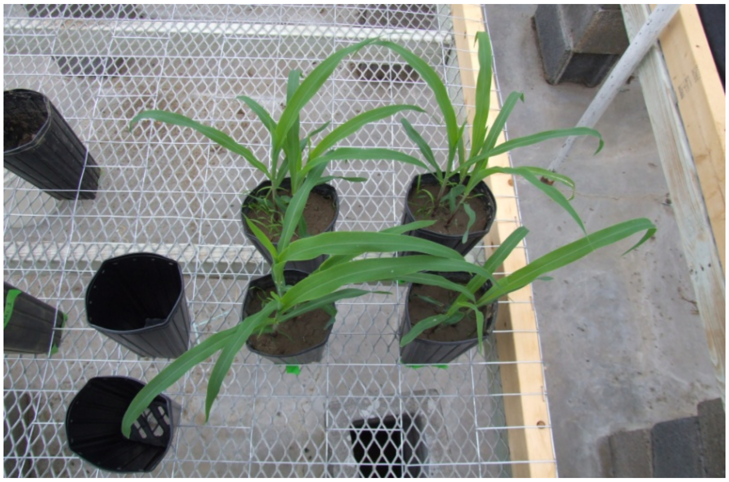
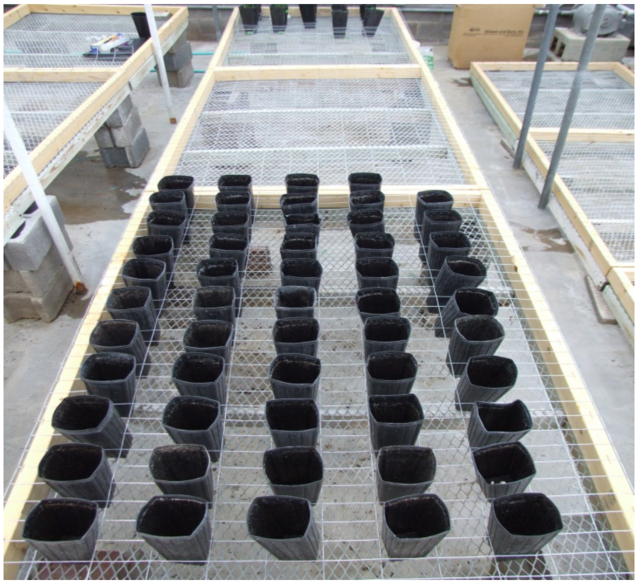
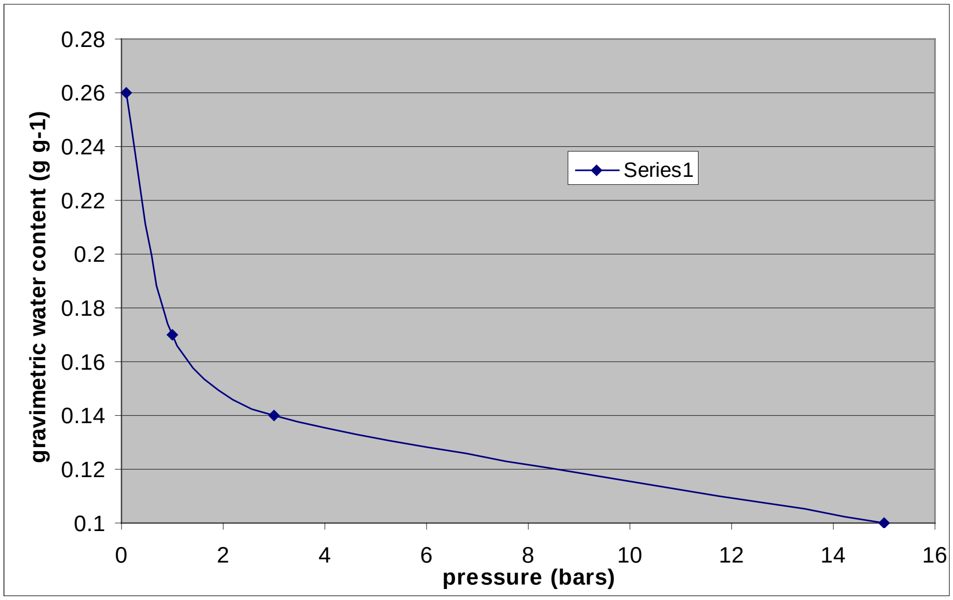


Figure 11: Modified shelving for Greenhouse.



Upon arrival, the biochars (Table 9) were passed through a 2-millimeter (mm) sieve to achieve a uniform particle size for the greenhouse studies. A soil water retention curve was calculated (Figure 12) to determine the amount of water needed to exceed water holding capacity and initiate leaching.

Figure 12: Water Holding Capacity (WHC) for unamended Musgrave Soil.



Germination rates were established for all application rates, and plant height measurements were continually performed. In addition, porometer readings were conducted to assess water stress; this measure of stomatal conductance gives insight into the soil water availability. Early observations of plant growth characteristics led to preliminary conclusions regarding optimal biochar feedstocks and the effect of charring parameters on resultant biochar properties. Applications of Food Waste biochar compared to Dairy Manure biochar demonstrate some of these effects and differences.

3.1 Food Waste Biochar

Food Waste biochar that was produced under all charring temperatures proved to have the lowest total biomass production (sum of above and below ground biomass production) and germination, in comparison to all the other biochars tested. The application rate of Food Waste biochar, produced at both 400 °C and 600 °C, resulted in decreased biomass production (Figure 13). However, at a charring temperature of 600 °C, greater application rates resulted in increased germination (Figure 14). Therefore, although application of Food Waste biochar resulted in the lowest rates of corn growth, as the charring temperature increases the corn growth improves (Figure 15). Overall, Food Waste biochar produced the smallest plants, but its inhibiting factors for growth decreased as the charring temperatures increased (Figures 16 and 17).

Figure 13: Corn growth (total biomass) as a function of Food Waste biochar addition (400°C and 600°C).

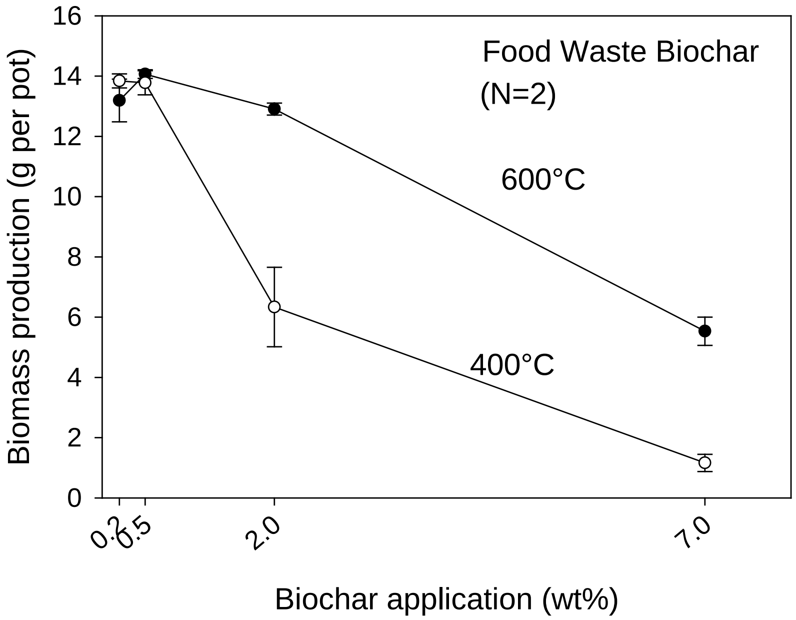


Figure 14: Germination of corn after different application rates of Food Waste biochar (400°C or 600°C).

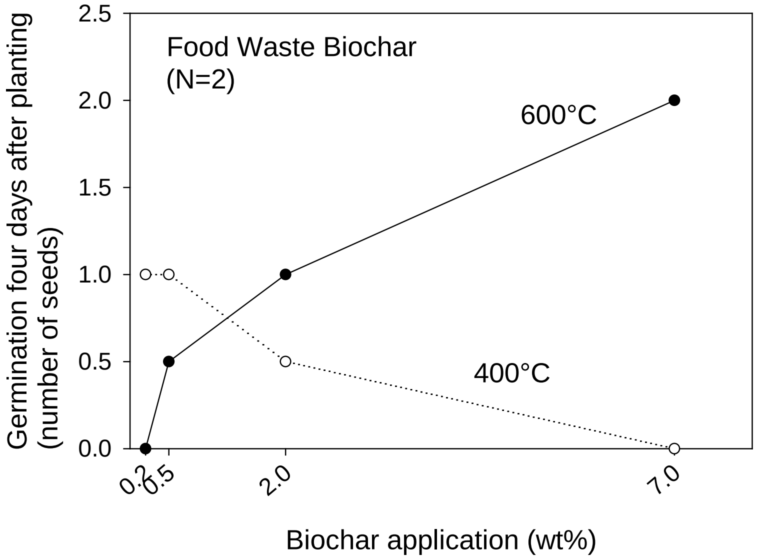


Figure 15: Corn growth as a function of Food Waste biochar application (produced at various temperatures)

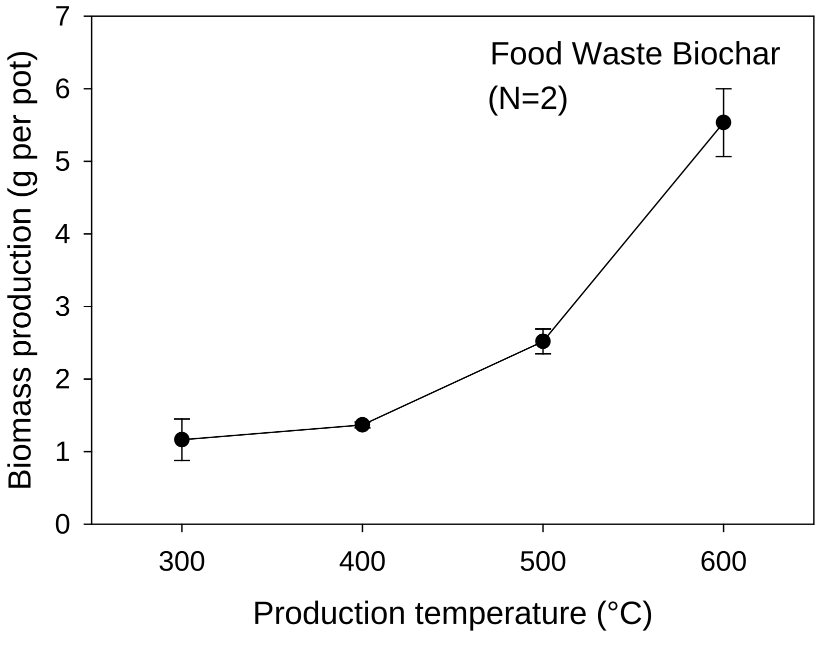


Figure 16: Plant growth increases as a result of increased charring temperatures.

Listed from left to right with all receiving the same seven percent application rate of biochar: Food Waste 300°C, Food Waste 400°C, Food Waste 500°C, Food Waste 600°C, Control (no biochar additions).

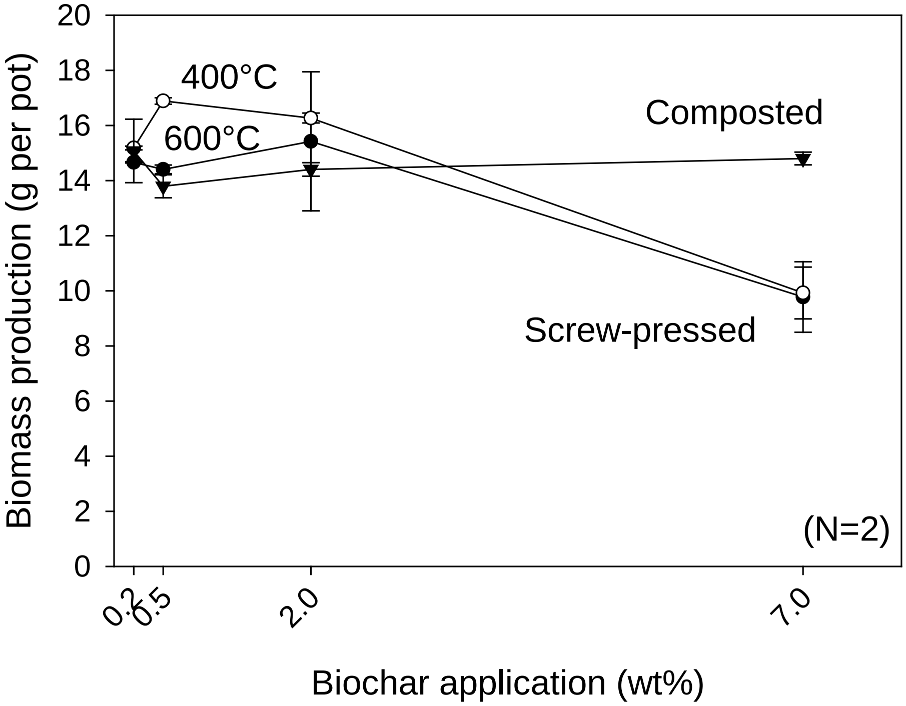
Figure 17: Food Waste biochars at 500°C production temperature with varying char application rates.

From left to right: seven percent, two percent, 0.5 percent, 0.2 percent, Control (no biochar additions).

3.2 Dairy Manure

Application of composted Dairy Manure biochar resulted in robust growth rates. As the application rate increased, so too did biomass production (Figure 18). The growth response to additions of Screw-pressed Dairy Manure, however, was depressed at high application rates. Foliar analyses may clarify whether nutrient deficiency explains this behavior.

Figure 18: Biomass production as a function of adding biochar produced from screw-pressed digested (pyrolyzed at 400 or 600°C) or composted dairy manure (pyrolyzed at 500°C).



3.3 Crop Harvest

Initially, all above ground biomass was clipped at the base of the corn stalk and dried in a 105 °C oven. The biomass was then weighed and the weights recorded for further root:shoot ratio assessment. The root wads were then manually separated from the potting soil, washed and photographed. Once washed of any adhered biochar and soil particles, the roots were dried in a 105 °C oven, removed, and weighed again. The above ground biomass and the roots were then roughly ground. Based on the root:shoot ratios of the dried biomass, the appropriate ratios of each were combined to create a representative whole plant sample.

The above ground biomass was ground separately from the roots due to an experimental observation made at the time. The roots, in most cases, had grown through the biochar particles, trapping them with rootlets, and generally becoming intertwined with small biochar particles. These particles did not separate from the roots with the initial washing, and therefore more care had to be taken to remove these particles prior to grinding. Combining the above and below ground biomass was done prior to ball-milling, which entailed milling one gram of the combined whole plant sample to a very fine powder. The samples were then weighed for total carbon (C) and nitrogen (N) using a combustion method. The remainder of the roughly ground biomass was used for other analyses including total nutrient analysis via inductively coupled plasma mass spectrometry (ICP-MS).

Table 14 presents a notable trend: for all biochars, total N uptake decreased as biochar application rates increased. It is hypothesized that some level of N immobilization occurs when the biochar mass in the soil reaches a critical level, and that N immobilization decreases with increasing charring temperature, which could be a result of lower amounts of volatile matter found in biochars produced at greater temperatures. However, simple correlations between biochar production temperature on N uptake and volatile matter on N uptake were not observed (Figure 19 and Table 15, respectively). Instead, as shown in Table 15, stronger relationships were observed between the N content, C/N ratios and N uptake. It is not clear if these relationships indicate that volatile matter represents the easily mineralizable fraction of biochar, or whether the N content is indeed a more important criterion. It is clear, however, that certain elements (i.e., Na) are detrimental to crop growth as their concentrations increase. Therefore, biochars high in Na should be applied at lower rates than those that have low Na concentrations.

After harvest, the soil and biochar potting mixtures were retained for future work. The pots were stored in a cool, darkened area that closely represents field conditions. The pots were watered monthly to allow the biochars to age, as they would if applied in the field.

Table 14: Plant growth and nitrogen uptake in response to biochar application rates.

Feedstock	**Total Biomass (g/pot)**				**N (mg/g dry matter)**				**N uptake (mg/pot)**			
	Biochar Application Rate (%)				**Biochar Application Rate (%)**				**Biochar Application Rate (%)**			
	0.2	**0.5**	**2.0**	**7.0**	**0.2**	**0.5**	**2.0**	**7.0**	**0.2**	**0.5**	**2.0**	**7.0**
Composted Dairy Manure 500 °C	15.07	13.79	14.40	14.80	9.01	9.86	9.20	8.67	13.60	13.61	13.26	12.82
Digested Dairy Manure screw pressed 300 °C	14.11	14.87	16.22	8.58	10.13	8.93	9.16	9.16	14.32	13.31	14.85	7.85
Digested Dairy Manure screw pressed 400 °C	15.18	16.89	16.27	9.92	9.96	9.59	10.26	8.47	15.11	16.18	16.68	8.39
Digested Dairy Manure screw pressed 500 °C	15.45	15.57	15.69	14.29	8.14	9.27	9.10	9.89	12.57	14.35	14.22	14.18
Digested Dairy Manure screw pressed 600 °C	14.66	14.41	15.42	9.77	8.88	9.59	9.15	8.93	13.02	13.82	14.28	8.64
Food Waste 300 °C	14.77	13.69	6.34	1.16	12.03	16.89	13.56	9.37	17.67	23.12	9.06	1.09
Food Waste 400 °C	13.84	13.78	9.74	1.37	11.84	9.31	13.45	9.76	16.33	12.83	12.97	1.34
Food Waste 500 °C	14.75	15.35	12.18	2.52	14.12	12.62	10.41	9.88	21.08	19.41	12.77	2.50
Food Waste 600 °C	13.19	14.07	12.91	5.53	11.25	10.07	9.92	10.56	14.75	14.18	12.82	5.80
Paper Mill Waste 300 °C	15.71	15.40	14.16	9.58	9.57	9.72	10.36	9.73	15.07	14.97	14.72	9.33
Paper Mill Waste 400 °C	13.23	14.14	13.05	4.81	10.48	10.87	9.65	9.31	13.77	15.27	12.59	4.52
Paper Mill Waste 500 °C	16.03	14.09	13.79	14.91	10.53	10.06	9.99	9.20	16.92	14.20	13.75	13.73

Table 14 continued

Feedstock	Total Biomass (g/pot)				N (mg/g dry matter)				N uptake (mg/pot)			
	Biochar Application Rate (%)				Biochar Application Rate (%)				Biochar Application Rate (%)			
	0.2	0.5	2.0	7.0	0.2	0.5	2.0	7.0	0.2	0.5	2.0	7.0
Paper Mill Waste 600 °C	14.84	14.04	16.58	14.90	10.37	10.47	9.87	9.66	15.42	14.72	16.33	14.45
Wood Waste 500 °C	14.81	14.39	13.04	12.12	10.37	10.49	8.79	9.51	15.32	15.09	11.46	11.57
Yard Waste Fall / Leaves 500 °C	14.99	14.54	14.00	12.54	8.56	9.52	9.39	9.26	12.83	13.86	13.14	11.61
Yard Waste Summer / Grass 500 °C	15.07	16.22	15.93	7.51	9.71	11.92	9.72	9.91	14.65	19.30	15.41	7.31
Yard Waste Winter / Brush 500 °C	15.08	13.57	15.04	12.75	9.00	10.25	9.95	9.05	13.61	13.93	14.97	11.50

Figure 19:Effect of Biochar Production Temperatures on Plant Nitrogen uptake (mg/pot).

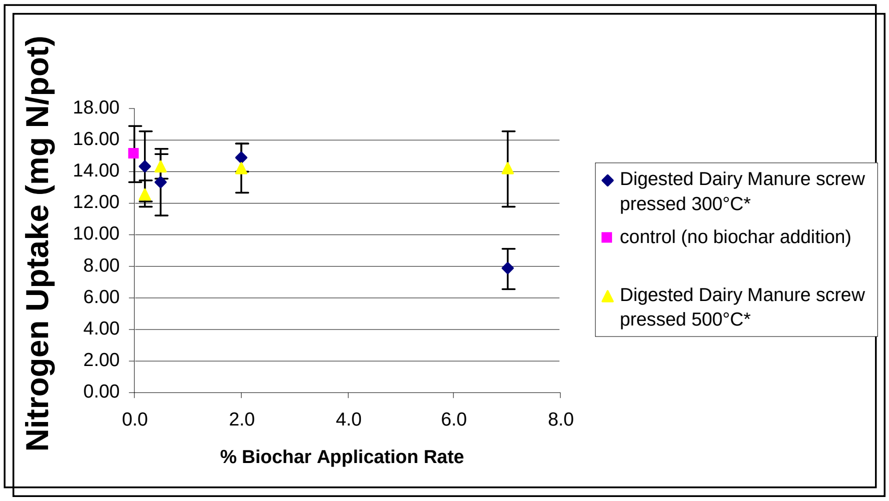


Table 15: Correlations (r^2) between biochar properties and biomass production or N uptake

N=32; except specific surface area

N=20; significant correlations at P<0.05 are shown in bold.

Biochar properties	Biomass production			
	Biochar application rates (w/w)			
	0.2%	0.5%	2.0%	7.0%
Bulk density	-0.005	0.026	-0.002	0.002
SSA (CO$_2$)[a]	-0.144	-0.060	-0.163	**-0.246**
pH (water)	0.063	**0.234**	**0.124**	0.001
EC	0.003	**0.146**	-0.006	-0.108
Fixed Carbon (ASTM)	-0.036	-0.053	0.012	0.013
Volatile Matter (ASTM)	0.078	-0.013	0.004	-0.007
Ash (ASTM)	0.100	0.088	0.009	-0.025
C	-0.036	-0.062	-0.031	0.000
N	0.002	0.033	**-0.131**	**-0.261**
C:N ratio	-0.077	**-0.241**	-0.020	-0.025
CEC	0.074	**0.124**	**0.131**	0.037
Available Ca	0.006	0.002	0.002	-0.026
Available K	0.042	**0.261**	0.002	-0.017
Available Na	-0.007	-0.000	**-0.178**	**-0.447**
Available Mg	0.006	**0.140**	0.109	0.003
Total P	0.021	**0.289**	**0.136**	0.071
Total Ca	-0.023	0.055	0.049	0.029
Total K	0.051	**0.498**	**0.167**	0.015
Total Mg	0.084	**0.411**	**0.192**	0.004
Total Na	-0.020	-0.006	**-0.133**	**-0.358**
	N uptake			
N	**0.269**	**0.342**	**0.152**	0.011
C:N	**-0.226**	**-0.239**	**-0.208**	-0.100

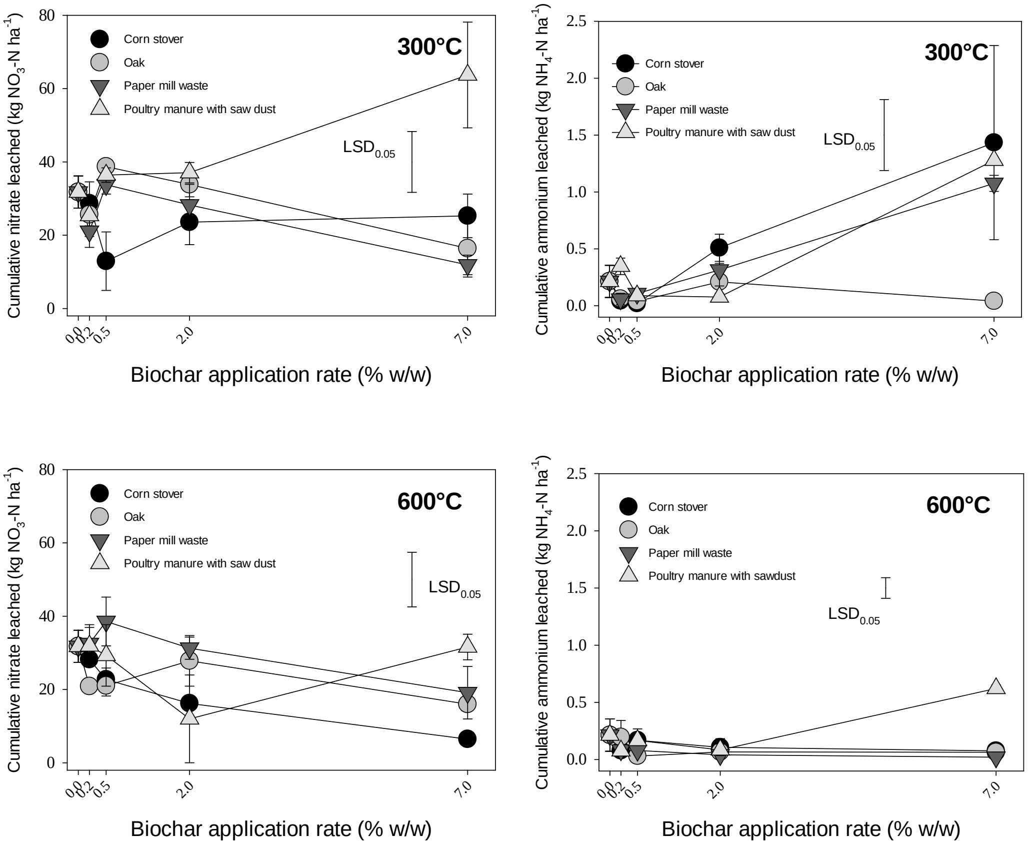
[a] The correlation was skewed by the low surface area of poultry manure biochar; excluding poultry manure biochar yields $r^2<0.15$ ($P>0.1$)

4 Task 5: Nutrient Leaching from Soils

Approximately 24 hours after each watering event, leachate bottles positioned beneath pots containing soil amended with wood waste-, paper mill waste-, poultry manure- or crop residue- (corn) biochars (300 °C or 600 °C) were checked, and any bottle containing leachate was taken to the laboratory. At the laboratory, the volume of leachate was recorded, and a representative subsample (five percent by volume) removed from each bottle. Subsamples were stored in the freezer prior to analysis for nitrate and ammonium via segmented flow analysis.

Figure 20 presents data on the cumulative leaching losses over the growth period. More leaching of nitrate occurred than ammonium. Leaching of nitrate increased with additions of poultry manure biochar produced at 300 °C. This leaching was likely due to the fact that poultry manure biochar contains large concentrations of mineral N and easily mineralizable organic N. Leaching of ammonium also increased with additions of all biochars, except those from the N-poor woody feedstocks. The most interesting result was the significant decrease in both ammonium and nitrate leaching for biochars produced at 600 °C. Therefore, as with feedstock type, it appears that temperature has an effect on leaching.

Figure 20: Nitrogen leaching losses with different application rates of biochar.



5 Task 6: Agronomic and Environmental Impacts

The objectives of the field studies were to:

- Determine the effects of amount to optimize positive effects on maize (i.e., corn) productivity
- Identify the effects of application frequency
- Quantify the effects of biochar addition on N fertilizer reduction
- Assess nitrous oxide emissions reduction as well as nitrogen leaching reduction with biochar addition

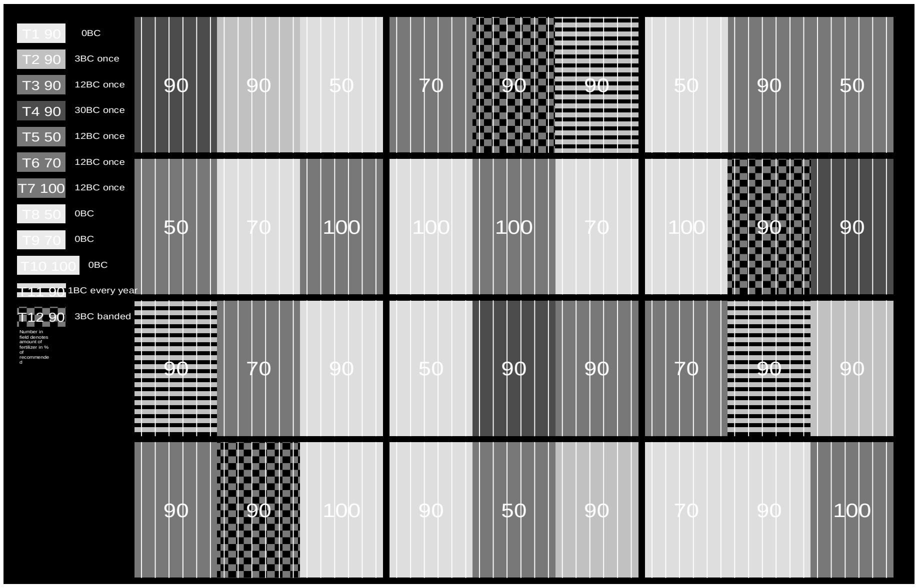
The biochar used in the field studies was produced by BEST Energies, Inc. (56 Gindurra Road, Somersby, NSW 2250 Australia). It was generated from corn stover under slow pyrolysis conditions at a production temperature of 600 °C. The field studies consisted of 36 plots; 12 forms of treatment were applied to various plots, as described in Table 16 and shown on Figure 21.

Table 16: Treatment description.

Treatment	Length of plot (m)	Width of plot (m)	Plot size (m^2)	Amount of char (tons/ha)	Amount of N fertilizer[a] (% of recommended)
1	7.5	4.5	33.75	0	90
2	7.5	4.5	33.75	3	90
3	7.5	4.5	33.75	12	90
4	7.5	4.5	33.75	30	90
5	7.5	4.5	33.75	12	50
6	7.5	4.5	33.75	12	70
7	7.5	4.5	33.75	12	100
8	7.5	4.5	33.75	0	50
9	7.5	4.5	33.75	0	70
10	7.5	4.5	33.75	0	100
11	7.5	4.5	33.75	1	90
12(banding)	7.5	4.5	33.75	3	90

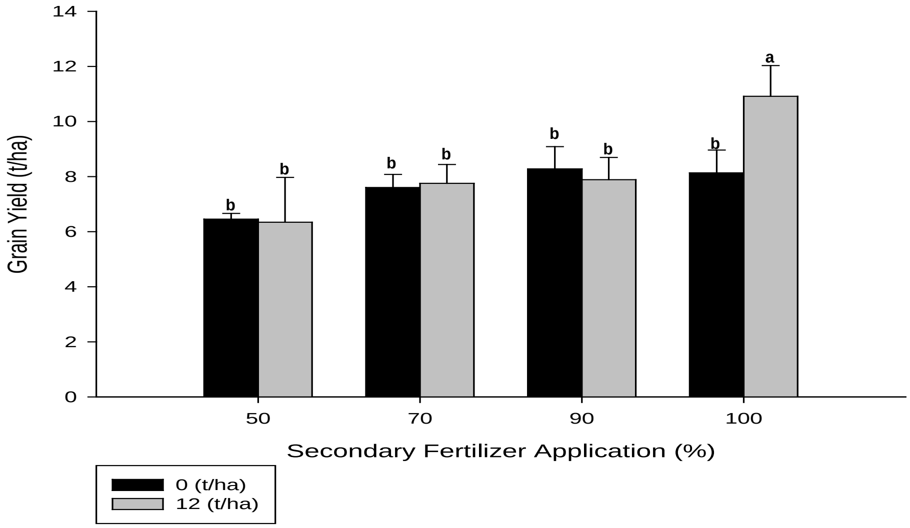
[a] Fertilizer application rates have been reduced in plots with higher applications of biochar to assess the nutrient retention capabilities of biochar. The fertilizer reductions in char amended plots should not affect the yield response due to the added nutrient retention qualities of char.

Figure 21: Field Research Plot Map.



The studies assessed greenhouse gas emissions (N_2O) from amended plots as well as nitrogen use efficiency and crop productivity. In 2009, free draining lysimeters were added to a subset of the plots, and post-ammonia side-dress application combined with a nitrogen experiment using ^{15}Nstable-isotope-labeled fertilizer, which allowed for assessment of the total nitrogen budget of the amended plots that included plant uptake, leaching, and gaseous nitrogen losses. Each aspect was quantified by measuring ^{15}N concentrations. Results indicated that nitrogen leaching was significantly decreased, and crop yields increased, where 100 percent fertilizer was applied with biochar (Figures 22 and 23; Guerena et al. 2012).

Figure 22: Corn grain yield as affected by biochar additions (n=3).



Student's T α=0.05

Figures 23 and 24 show that nitrogen losses at different fertilizer application rates were significantly reduced in the presence of biochar, which may have been the reason for the increased grain yields seen in 2009.

Figure 23: Leaching losses from soil cropped to corn (n=3).

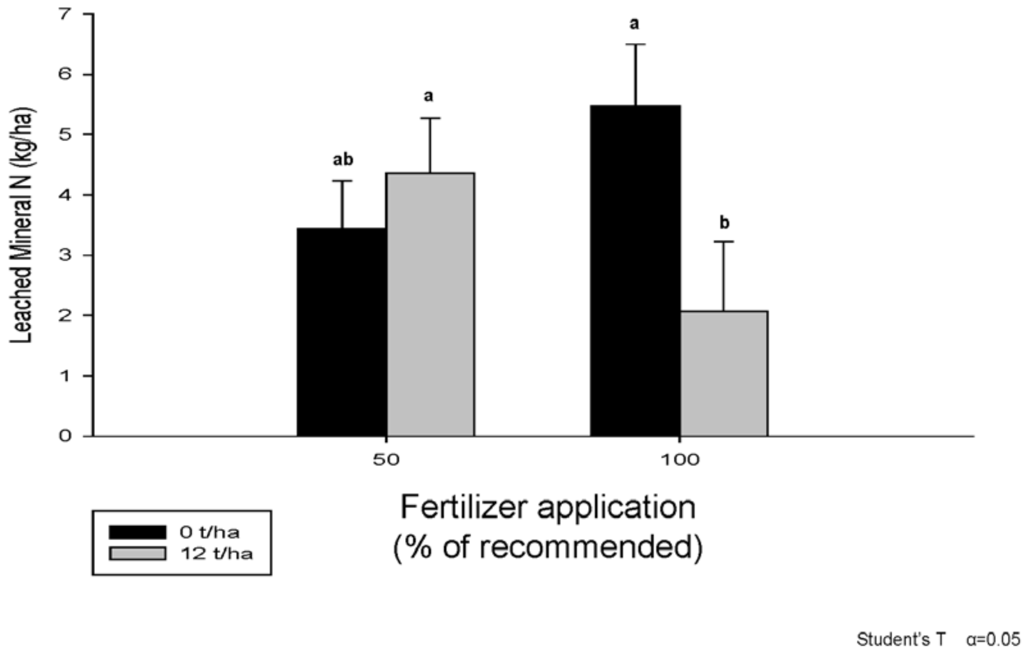


Figure 24: Fertilizer recovery in corn using ^{15}N-labeled N fertilizer (n=3).

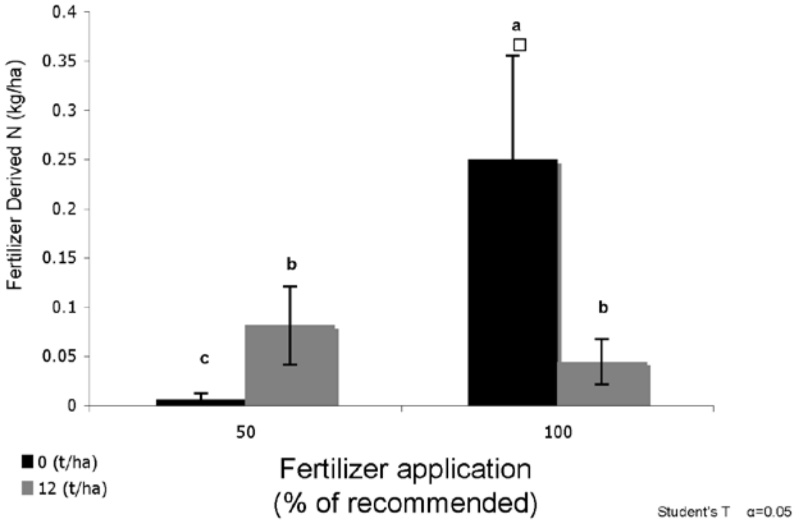


Table 17 and Table 18 show the harvest data for the field studies since they were begun in 2007. The 2007 harvest was lower across all treatments due to poor weed control. Addition of biochar was observed to increased crop yields only at high nitrogen fertilizer application rates (Table 17). Addition of biochar did not significantly decrease yield even at 30 tons per hectare (t/ha) (Table 18).

Table 17: Maize grain yield with increasing nitrogen fertilization following biochar soil application in 2007.

	2007		2008		2009		2010	
Secondary N Fertilizer Application Rate (%)	Control	12 t ha^{-1} Biochar	Control	12 t ha^{-1} Biochar	Control	12 t ha^{-1} Biochar	Control	12 t ha^{-1} Biochar
50	5.66	3.38	6.98	6.83	6.50	6.64	7.74	7.25
70	4.27	3.38	7.37	8.28	8.01	8.19	7.93	8.50
90	4.74	4.20	9.26	8.14	8.50	7.93	9.19	8.64
100	4.50	4.66	10.41	11.38	8.59	9.21	8.76	8.93

Table 18: Maize grain yield on a New York Alfisol amended with biochar in May 2007 (+/-SE, n=3). Secondary fertilizer application is 90% of recommended rate.

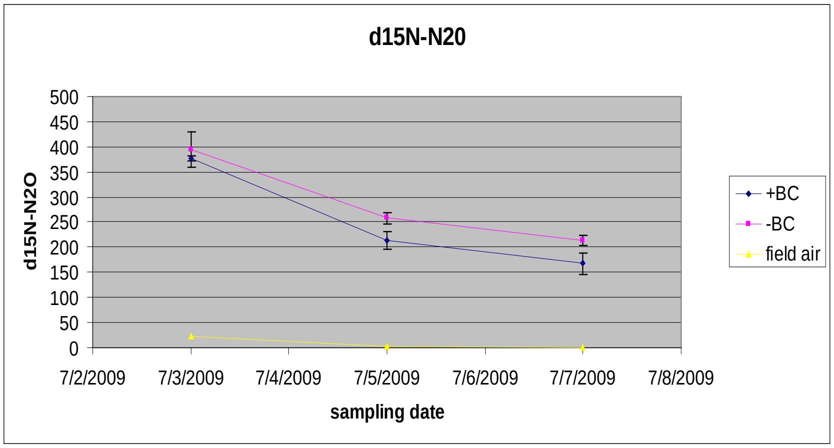
	Year			
Biochar (t ha^{-1})	2007	2008	2009	2010
0	4.74	9.26	8.50	9.20
3	4.11	7.80	8.51	9.01
12	4.19	8.14	7.93	8.65
30	4.02	7.66	6.59	7.84
1 yr^{-1}	4.05	7.48	8.56	8.98

5.1 N_2O emissions from Biochar-Amended Soils

The data collected on N_2O emissions was a subset of the larger project. Recent studies have shown that biochar addition to highly weathered soils may reduce N_2O emissions. However, it was not clear if similar effects would be seen in temperate soils, such as those soils found in NYS. The vented-static chamber method was used to capture nitrous oxide emissions. Treatments 1 and 3 (Table 16) were chosen for emissions comparisons. For both, 90 percent of the recommended application rate of 120 pounds per acre post ammonia side-dress nitrogen was applied.

Emissions monitoring occurred during the 2007, 2008 and 2009 field seasons. The plots amended with biochar were found to emit, on average, 8.65 µg/sec/m^2 (standard error 1.68), which was not significantly lower than plot without biochar additions (n=21; 8.74 µg/sec/m^2 (SE 1.78)). The highest emissions were noted immediately after nitrogen fertilization, which showed a marked decrease through biochar additions ($p < 0.05$). As stated previously, in 2009 the post ammonia side-dress application was labeled with ^{15}N to facilitate the tracking of nitrogen movement through the system. Figure 25 shows the three gas sampling sessions.

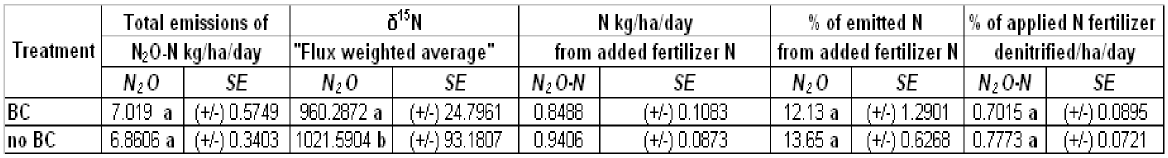
Figure 25: Measured ^{15}N- N_2O at three sampling dates. The ^{15}N was measureable well above background field air levels.



5.1.1 Results of N-15 Side-Dress Analyses

The 2009 labeled side-dress work showed that in the biochar amended plots 0.70 percent (SE 0.09) of applied nitrogen was emitted as N_2O, in contrast to the unamended plots, which showed a loss of 0.78 percent (SE 0.07) of applied nitrogen. The $\delta^{15}N$-N_2O was significantly lower with biochar application. However, average emissions for the three days were only slightly reduced ($p = 0.207$) with biochar application (Table 19).

Table 19: $\delta^{15}N$-N_2O emissions monitoring in 2009.



Treatment	Total emissions of N_2O-N kg/ha/day		$\delta^{15}N$ "Flux weighted average"		N kg/ha/day from added fertilizer N		% of emitted N from added fertilizer N		% of applied N fertilizer denitrified/ha/day	
	N_2O	*SE*	*N_2O*	*SE*	*N_2O-N*	*SE*	*N_2O*	*SE*	*N_2O-N*	*SE*
BC	7.019 a	(+/-) 0.5749	960.2872 a	(+/-) 24.7961	0.8488	(+/-) 0.1083	12.13 a	(+/-) 1.2901	0.7015 a	(+/-) 0.0895
no BC	6.8606 a	(+/-) 0.3403	1021.5904 b	(+/-) 93.1807	0.9406	(+/-) 0.0873	13.65 a	(+/-) 0.6268	0.7773 a	(+/-) 0.0721

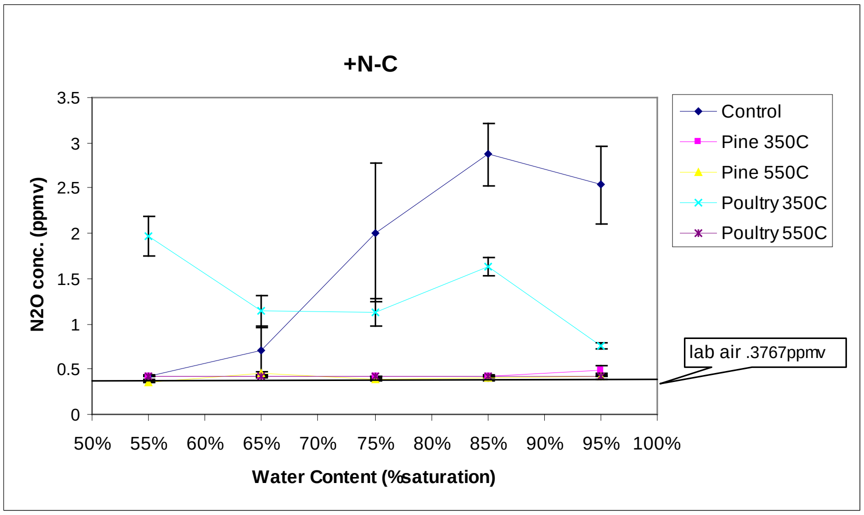
A controlled incubation experiment was performed to further investigate the mechanisms behind the reduction, and answer the following:

- Is nitrate availability reduced by biochar; therefore reducing nitrous oxide emissions?
- Is labile carbon availability reduced by biochar; therefore reducing nitrous oxide emissions?
- Does biochar change the water-filled pore space; therefore changing nitrous oxide emissions?

Pine and poultry manure biochars, produced at 350°C and 550°C, were chosen for the experiment. A sand/kaolinite mixture was inoculated with a microbial extract from a biochar-rich soil (Cheng et al. 2008), mixed with biochar at increasing levels of water-filled pore space (WFPS),and leaf extracts were added to the jars as a carbon source. All jars received full Hoagland solution, either with or without nitrogen. Nitrous oxide emissions, measured using gas chromatography, were found to increase with increasing water filled pore space, except where biochar from poultry litter (pyrolyzed at 350°C) was used. With increasing pyrolysis temperature, nitrous oxide emissions decreased (Figure 26).

Figure 26: Nitrous oxide concentrations in incubation chambers

Without N and C addition (-N-C) (first figure), with only N addition (+N-C) (second figure), with only C addition (-N+C) (third figure), and with addition of both N and C (+N+C) (fourth figure).



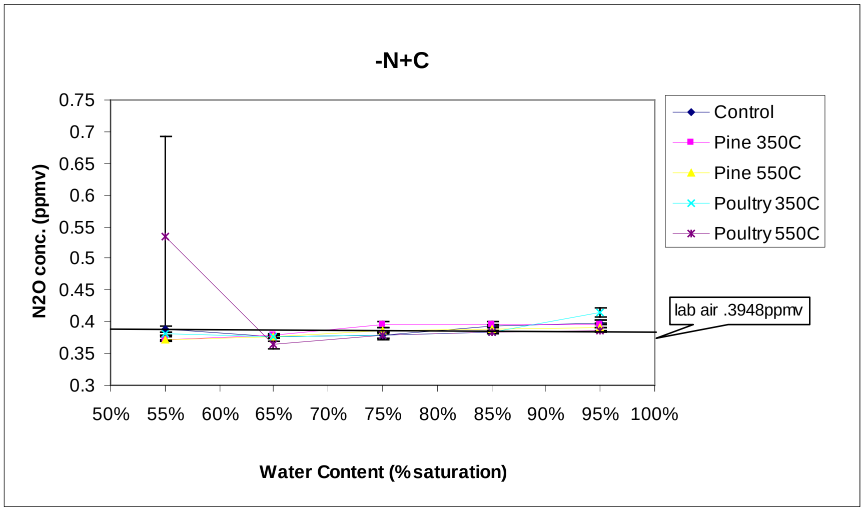
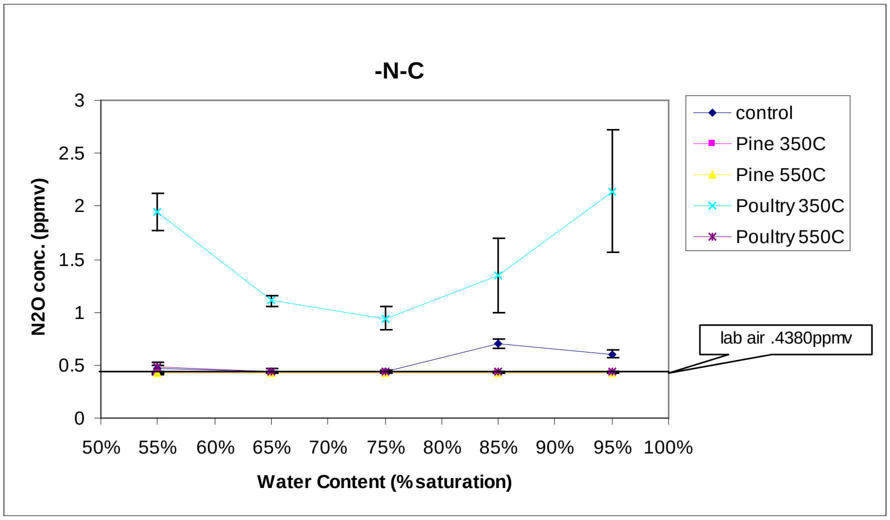
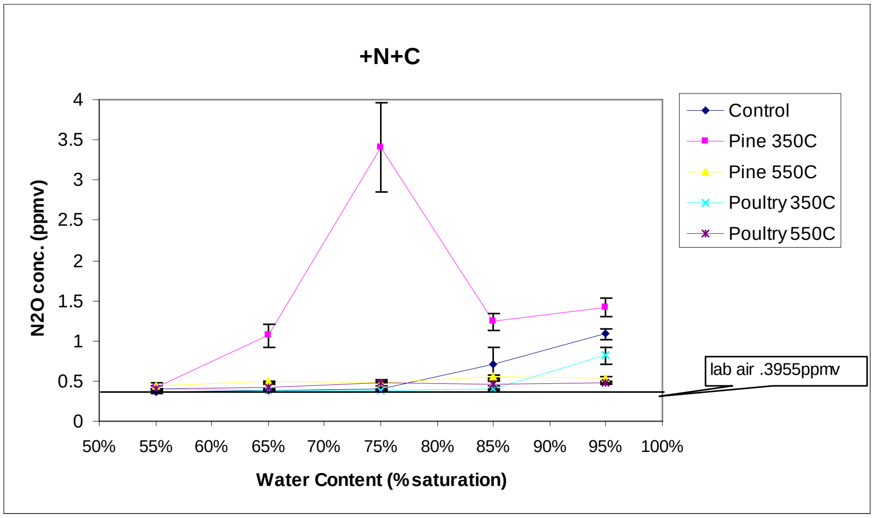


Figure 26: continued





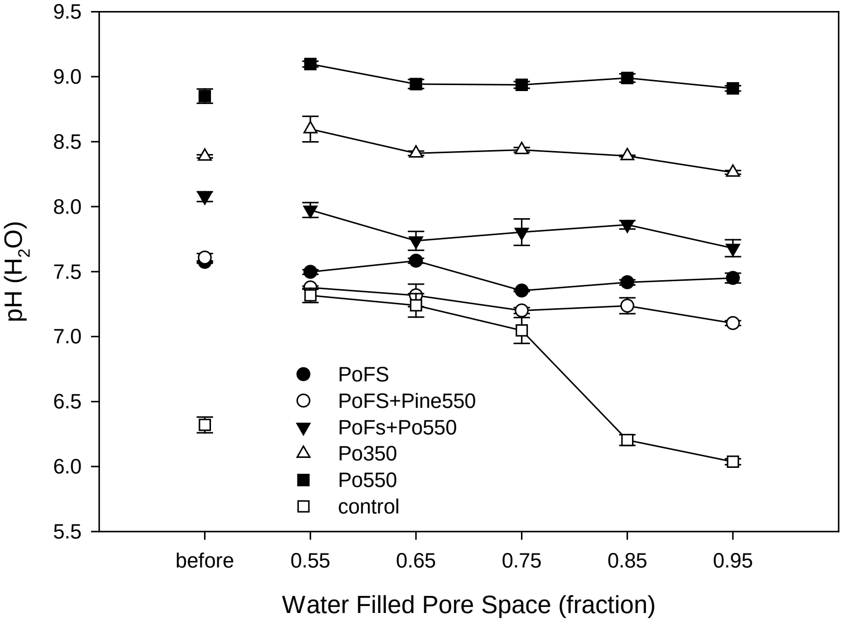
Experiments are underway, using unpyrolyzed feedstocks, to explain why the emissions associated with low-temperature, poultry manure biochar were so high. The questions that will hopefully be answered by these experiments include the following:

- Will the uncharred poultry feedstock emit more than poultry pyrolyzed at 350°C?
- Will emissions be reduced if manure is mixed with a biochar (poultry or pine) produced at 550°C?
- Do lignacious biochars have a stronger reductive effect on emissions?

These experiments should also provide additional data on pH, KCl extractable NH_4^+, and NO_3^-N (both pre- and post-incubation).

The acetylene block technique (Ryden et.al. 1979) is also being used during the experiments. The technique relies on the ability of acetylene gas to inhibit the reduction of N_2O to N_2. (N_2 is inherently difficult to measure due to its high natural concentrations in the atmosphere.) Overall denitrification nitrogen loss can therefore be measured as N_2O. As a result, labeled N compounds will not be required. Initial results have shown significant changes in pH values, which may also affect emissions (Figure 27).

Figure 27: pH values before and after incubation of original feedstock (FS) of poultry manure with or without addition of pine and poultry manure biochars pyrolyzed at 350°C or 550 °C.



6 Task 7: Refining the Models

6.1 Model 1: Pyrolysis of Residential Yard Waste – an Independent Venture Located on County Land

6.1.1 Assumptions

6.1.1.1 Expenses: Pyrolysis Facility

This model was based on a facility that can process two tons (dry weight) per hour of feedstock, which has an average water content of 45 percent. The assumption was also made that the facility would operate 4,536 and 4,928 hours in years one and two, respectively, and 7,392 hours per year for years three through 10. Additionally, the facility would operate as an independent venture. Based on the assumptions, the facility would produce 877 kW per hour and 1,573 pounds char per hour of operation[1].

Such a facility would cost somewhere in the range of $12 million to15 million for a full project installation, including the costs of installing generating capacity, site purchase, planning, construction and infrastructure. And as previously discussed, location specific factors could increase these costs. Over time, however, costs associated with future installations should decrease, as experience with installations accrues. The facility would also have associated operational costs including labor associated with operation and maintenance, contingencies associated with facility commissioning, and office/administrative expenses. These capital and operational costs (Tables 20a and 20b) were determined in consultation with Best Energies Inc., based on their experience to date in the U.S. and Australia.

6.1.1.2 Revenues: Biochar

Based on the assessment of potential biochar markets discussed previously in this report, the assumption was made that the biochar could be sold for $200 per ton as the base model, with a low of $100 per ton and a high of $300 per ton.

6.1.1.3 Revenues: Tipping Fees

Based on the previous assessment, the assumption was made that the facility would receive a tipping fee of $50 per ton as the base model, with a low of $35 per ton and a high of $75 per ton.

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[1] This data is refined once a specific location and range of feedstocks are identified.

6.1.1.4 Revenues: Carbon Trading Price

Based on the previous assessment, the assumption was made that the carbon trading price would be $10 per metric ton CO_2 as the base model, with a low of $4 per metric ton CO_2 and a high of $50 per metric ton CO_2.

6.1.1.5 Economic Analysis

Using the base model information previously provided, the economic analysis shows that the facility would have a positive net present value under both high and low investment costs (Table 20 and Table 21), assuming the cost of capital was five percent and the location based marginal price of electricity was 6 cents per kWh.

Analyses of the low and high models were also performed, to determine the minimum location based marginal price at which the electricity from the system would have to be sold for the project to be economically viable (Tables 22 and 23). Only in the low model would it be necessary to charge for electricity, which highlights the importance of the variables used in defining whether or not a model is viable. With the low model, a price ranging from 12 cents per kWh to 18 cents per kWh is required for the model to be viable.

Table 20: Summary of economic data for a facility operating over a 10 year period; Capital Investment of $12M

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Initial investment	$ 12,000,000									
Revenue										
Electricity:	$ 238,684	$ 259,311	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967
Biochar:	$ 713,513	$ 775,174	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762
Biochar CO2 Credits:	$ 89,065	$ 96,762	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143
Fossil fuel offset:	$ 14,361	$ 15,602	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403
Avoided emission:	$ 130,157	$ 141,405	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107
Tipping Fee:	$ 824,727	$ 905,856	$ 1,373,568	$ 1,388,352	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136
Costs										
Natural gas	($57,154)	($62,093)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)
Gross Margin	$ 1,953,353	$ 2,132,018	$ 3,212,810	$ 3,227,594	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378
Operating Cost										
Production costs (labor)	$ 302,168	$ 317,064	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696
Plant costs	$ 218,060	$ 222,930	$ 291,036	$ 305,617	$ 322,479	$ 342,061	$ 364,899	$ 391,645	$ 423,094	$ 460,218
Total operating cost	$ 520,228	$ 539,994	$ 701,732	$ 716,313	$ 733,175	$ 752,757	$ 775,595	$ 802,341	$ 833,790	$ 870,914
Net income	$ (10,566,875)	$ 1,592,024	$ 2,511,079	$ 2,511,281	$ 2,509,204	$ 2,489,622	$ 2,466,783	$ 2,440,037	$ 2,408,588	$ 2,371,465

Assumptions

Tipping fee for feedstock ($ per wet ton)	$ 50
Wholesale price for biochar per t	$ 200
Carbon trading value $ per metric ton CO2	$ 10
Location based marginal price $ per kW	$ 0.060
Net Present Value	$5,852,425
Cost of capital	5.00%

Table 21: Summary of economic data for a facility operating over a 10 year period; Capital Investment of $15M

	Year 1	Year 2	Year 3	Year 4	Year 5	Year 6	Year 7	Year 8	Year 9	Year 10
Initial investment	$ 15,000,000									
Revenue										
Electricity:	$ 238,684	$ 259,311	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967	$ 388,967
Biochar:	$ 713,513	$ 775,174	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762	$ 1,162,762
Biochar CO2 Credits:	$ 89,065	$ 96,762	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143	$ 145,143
Fossil fuel offset:	$ 14,361	$ 15,602	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403	$ 23,403
Avoided emission:	$ 130,157	$ 141,405	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107	$ 212,107
Tipping Fee:	$ 824,727	$ 905,856	$ 1,373,568	$ 1,388,352	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136	$ 1,403,136
Costs										
Natural gas	($57,154)	($62,093)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)	($93,139)
Gross Margin	$ 1,953,353	$ 2,132,018	$ 3,212,810	$ 3,227,594	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378	$ 3,242,378
Operating Cost										
Production costs (labor)	$ 302,168	$ 317,064	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696	$ 410,696
Plant costs	$ 218,060	$ 222,930	$ 291,036	$ 305,617	$ 322,479	$ 342,061	$ 364,899	$ 391,645	$ 423,094	$ 460,218
Total operating cost	$ 520,228	$ 539,994	$ 701,732	$ 716,313	$ 733,175	$ 752,757	$ 775,595	$ 802,341	$ 833,790	$ 870,914
Net income	$ (13,566,875)	$ 1,592,024	$ 2,511,079	$ 2,511,281	$ 2,509,204	$ 2,489,622	$ 2,466,783	$ 2,440,037	$ 2,408,588	$ 2,371,465

Assumptions

Tipping fee for feedstock ($ per wet ton)	$ 50
Wholesale price for biochar per t	$ 200
Carbon trading value $ per metric ton CO2	$ 10
Location based marginal price $ per kW	$ 0.060

Net Present Value	$2,995,283
Cost of capital	5.00%

Table 22: Minimum kWh location based marginal price at which the facility would be feasible; Capital Investment of $15M

	Low	Base	High
Tipping fee for feedstock ($ per wet ton)	$ 35	$ 50	$ 75
Wholesale price for biochar per t	$ 100	$ 200	$ 300
Carbon trading value $ per metric ton CO2	$ 4	$ 10	$ 50
Location based marginal price $ per kW	$ 0.182	$ -	$ -
Net Present Value	$781	$252,510	$19,827,218
Cost of capital	5.00%	5.00%	5.00%

Table 23: Minimum kWh location based marginal price at which the facility would be feasible; Capital Investment of $12M

	Low	Base	High
Tipping fee for feedstock ($ per wet ton)	$ 35	$ 50	$ 75
Wholesale price for biochar per t	$ 100	$ 200	$ 300
Carbon trading value $ per metric ton CO2	$ 4	$ 10	$ 50
Location based marginal price $ per kW	$ 0.119	$ -	$ -
Net Present Value	$869	$3,109,653	$22,684,361
Cost of capital	5.00%	5.00%	5.00%

6.2 Model 2: Pyrolysis in an Institutional Setting - Cornell University

In the future, an economic analysis will be performed for Model 2, as Cornell University represents an institution with significant land base, biomass resources, and burdensome waste streams. Additionally, there is a potential to treat county waste streams in the on-campus system, which would save the county the costs associated with its present disposal contracts.

Table 24: Cornell University Waste Streams: (1 ton = 0.74 cu yds)

Feedstock	Amount	Amount in tons/year
Yard waste[a]	2,000 cu yds/year	2,702.7 tons/year
Pre-ground pallet waste	1,000 cu yds/year	1,351.4 tons/year
Composting at Cornell[b]	8,000 tons/year	10,810.8 tons/year
Harford Farm-Dairy manure	Data forthcoming	Data forthcoming
Culled forestry cuttings[c]	1,000-1,500 tons woody biomass/year	1,000-1,500 tons woody biomass/year
Waste Vegtable Oil	6,000 gallons/year	750 tons/year
Landfilled waste[d]	4,589 tons/year	4,589 tons/year
Recycled waste	2263 tons/year	

[a] As defined by Cornell: shrub and tree prunings, grass clippings, leaf wastes, stumps (ground)

[b] Streams consist of cow manure, horse bedding, dining hall food wastes, landscaping debris, greenhouse wastes.

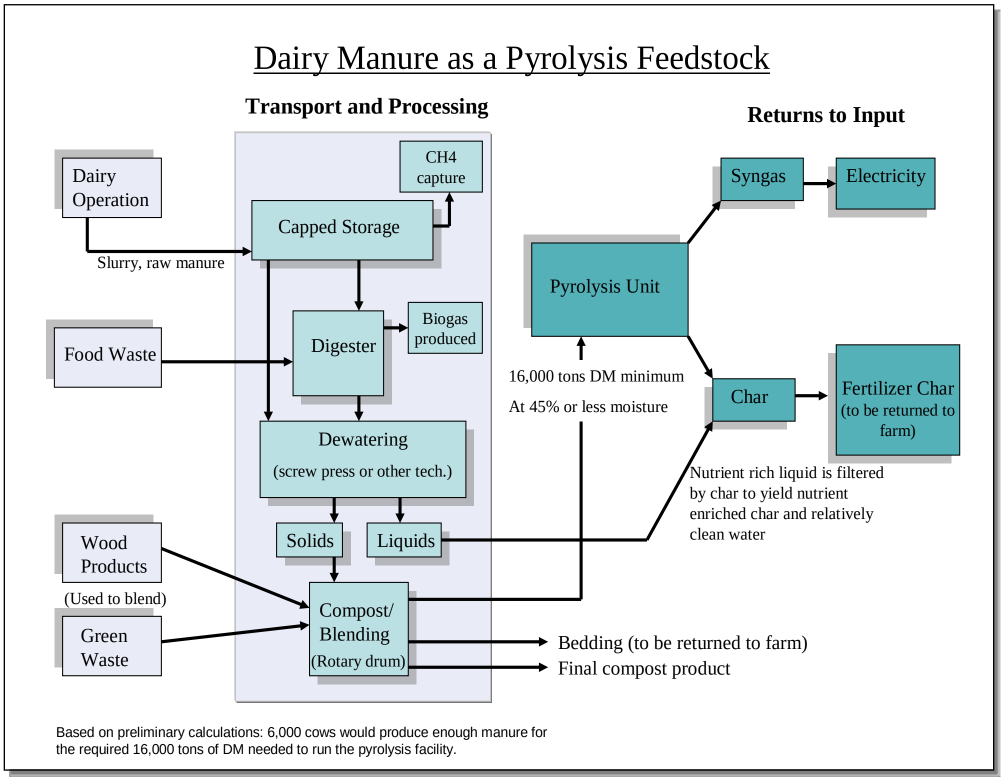
[c] Beginning in 2008 CALS forested properties (6,500 acres) will undergo a sustainable forestry effort where the above numbers are suspected to be generated annually for the next 15 years.

[d] High Acres Landfill in Angelica, NY or Ontario County Landfill.

6.3 Model 3: Pyrolysis for Manure Management

The proximity of a pyrolysis unit to an anaerobic digester would create the potential to use the excess solid fraction as a pyrolysis feedstock. There is also the potential of treating the nutrient-laden liquid fraction by filtering it through the biochar produced by the pyrolysis unit (Figure 28). The treated water could subsequently be used for irrigation, and if clean enough, animal drinking water. Although with the humid NYS climate, water is not as large of a problem for producers as elsewhere in the country. However, one will find clusters of farms where water may limit expansion. In these cases farmers may have to pay for a municipal water source. It has been estimated that one in every 20 producers may have an interest in a less expensive water source. Of course, transportation of water from a pyrolysis plant to the farm (via truck) could potentially negate any value of a source derived from the plant. The installation of piping from a large dairy to a pyrolysis plant, where nutrient-rich water is piped to the plant and treated water piped to the farm, could work, but this arrangement relies on the plant being in proximity to the farm and the farm requiring water.

Figure 28: Dairy manure as a pyrolysis feedstock.



Based on preliminary calculations: 6,000 cows would produce enough manure for the required 16,000 tons of DM needed to run the pyrolysis facility.

In the future, an economic analysis will be performed for Model 3. However, before it is, the following need to be addressed:

- The true costs of spreading manure (e.g., equipment, labor, etc.); the standard assumption is 1-2¢ per gallon.
- The costs of long-term storage of liquid manure and separated solids.
- The perceived value to a farm for waste handling.
- The cost per gallon of current manure management practices.
- The potential revenues that can be derived by a farm for manure processing; raw manure is estimated to be worth 2-3¢ per gallon due to nutrient content.
- The logistics/specifications that would potentially be required for off-site manure processing.

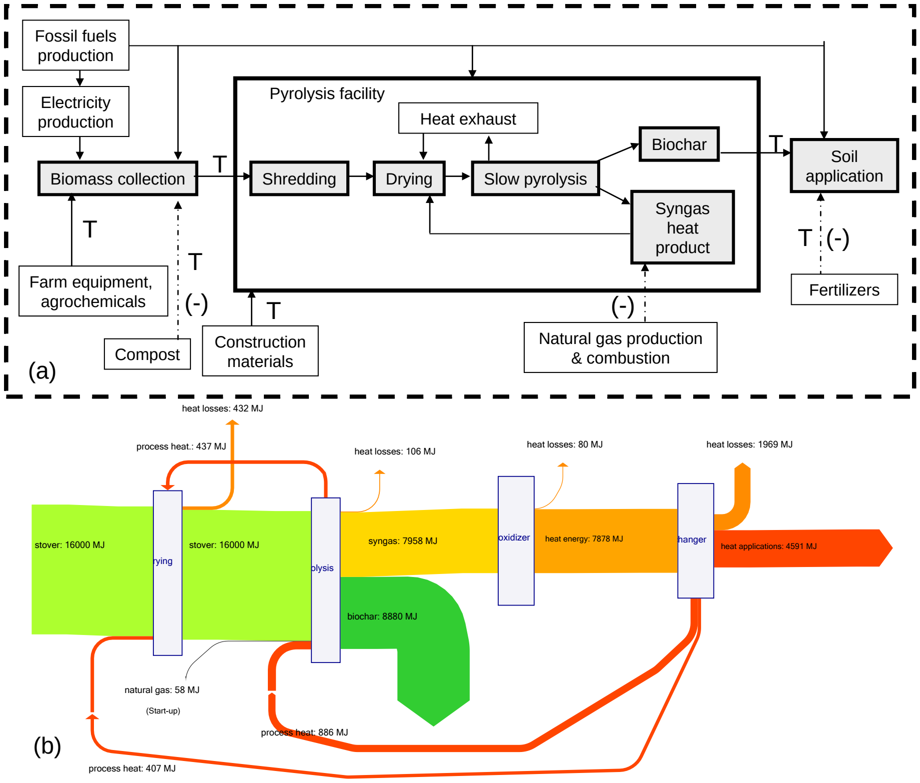
The feasibility of pyrolyzing poultry manure is also being assessed. However, the volume of poultry manure in NYS is not nearly as significant as the volumes associated with the dairy industry, and the consistency of poultry manure lends itself to easier processing as saleable compost (Wright and Graf 2004). However, officials in Oswego County officials have made it clear that the land base in Oswego County cannot support the land application of manure shipped to the county from Plainville Turkey (Onondaga County) forever.

6.4 Life-Cycle Assessment

Life cycle assessment was used to estimate the energy, climate change and economic impacts of bioenergy, biochar systems (Figure 29). The feedstocks assessed included agricultural residues (corn stover), yard waste and switchgrass energy crops.

Figure 29: Boundary conditions of the LCA and the energy flows.

T means transportation.



The greatest net energy production is associated with switchgrass (4899 megajoules per ton dry feedstock; Figure 30).

The net greenhouse gas emissions for both corn stover and yard waste are negative: -864 and -885 kg CO_2 equivalent (CO_2e) emissions reductions per tonne dry feedstock, respectively; 62 to 66 percent of these emission reductions are due to the carbon sequestration in biochar.

The system based on switchgrass was found to be a net greenhouse gas (GHG) emitter (+36 kg CO_2e/t dry feedstock), depending on the accounting method used for indirect land-use change impacts.

The economic viability of the system is largely dependent on the costs of feedstock production, costs of the pyrolysis plant, and the value of carbon offsets.

Biomass sources that require waste management, such as yard waste, have the highest potential for economic profitability ($69 per ton dry feedstock when CO_2e emission reductions are valued at $80 per ton CO_2e).

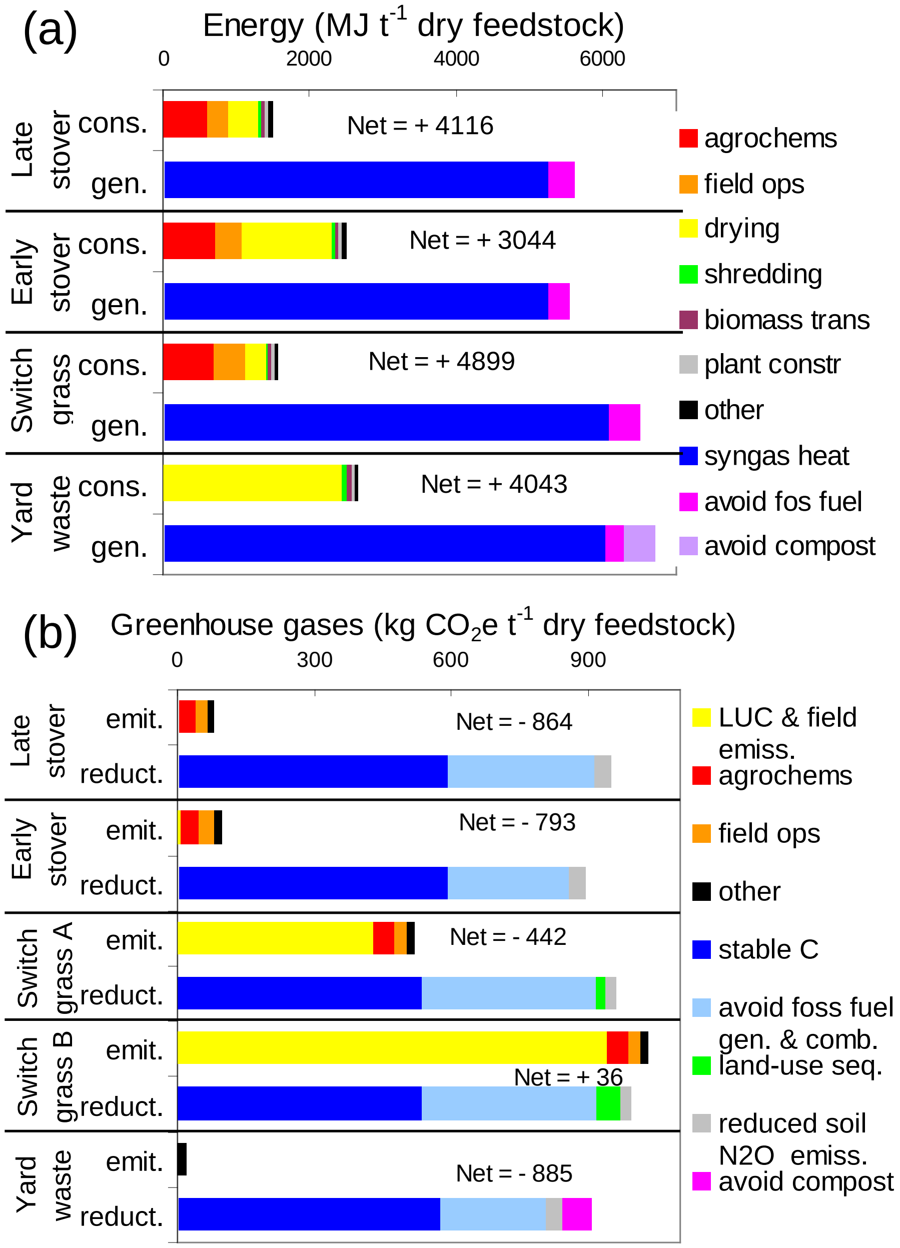
Transportation distance can significantly affect economic profitability.

At present, biochar may only deliver climate change mitigation benefits and be financially viable as a distributed system based on waste biomass.

Figure 30: Contribution analysis for net energy and net climate change impact.

(a) Contribution analysis for the net energy per dry tonne of late stover, early stover, switchgrass, and yard waste in biochar systems with bioenergy production. [Note: The top bar represents energy consumption, the bottom bar energy generated, and the difference the net energy.] Switchgrass A and B have the same energy contribution profile, and only scenario A is shown.

(b) Contribution analysis for the net climate change impact per dry tonne of late stover, early stover, switchgrass, and yard waste in biochar systems with bioenergy production. [Note: The top bar represents GHG emissions, the bottom bar GHG emission reduction, and the difference the net GHG emission balance. (LUC = land-use change.)



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Mitigation of Ecosystem Degradation by Bioenergy Using Biochar

Final Report
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