Cornell University

Introduction to Farm & Forest Greenhouse Gas Mitigation Opportunities

Information Sheet #1

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Information Sheet #1: OVERVIEW

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Fast Facts

- **Trends**: While carbon dioxide (CO_2) from fossil combustion accounts for about 80% of global greenhouse gas (GHG) emissions, methane (CH_4) and nitrous oxide (N_2O) are the primary source of GHG emissions on farms.
- **An imperative to act:** Methane impact on the atmosphere is 34 times more potent than CO_2 over 100 years (86 times more potent over 20 years). Nitrous oxide is 298 times more potent than CO_2 over 100 years. Small changes in these gases can have large impact.
- **A concern for implementation:** Climate change is changing temperature and weather with likely increase of rainfall intensity and droughts that affect agriculture.
- **An opportunity for proactive change:** While farms contribute GHG emissions, farms also have great potential to mitigate these emissions while providing other benefits such as energy savings, reduced air and water pollution, and increased profitability.

Introduction

Climate change caused by increased emission of greenhouse gases (GHG) to the atmosphere is an important issue that affects agriculture. Some agricultural practices emit GHG, while others reduce GHG emissions. Globally, agriculture is responsible for 20% of annual GHG emissions (IPCC, 2014). In the United States, agriculture is responsible for 8.3% of GHG emissions (US EPA, 2016). Agriculture can continue to advance management for reduced greenhouse gas emissions as a part of the global effort to curb climate change. For example, improving dairy diets has reduced enteric (methane-based) GHG emissions from dairy cows, and improved management of nitrogen fertilizer has reduced nitrous oxide emissions (a very potent GHG). Additionally, some agricultural practices have the potential to reduce GHG emissions from other sectors (e.g. bioenergy reducing emissions from fossil fuel electric generation, agricultural practices absorbing existing emissions by sequestering carbon in forests and soils).

Agricultural GHG emissions come primarily from three gases: methane (CH_4), nitrous oxide (N_2O), and carbon dioxide (CO_2). While CH_4 and N_2O emissions are much lower in volume than CO_2, these GHGs have a much greater ability to trap heat in the atmosphere. To simplify GHG accounting, each gas is assigned a value called the Global Warming Potential (GWP) that shows its ability to trap heat in the atmosphere compared to CO_2. The common unit for GWP is the carbon dioxide equivalent (CO_2e). Over a 100-year period, CH_4 and N_2O are 34 and 298 times more potent than CO_2, so they have GWP values of 34 and 298, respectively. Farms interested in mitigating emissions should focus on these three gases.

Concerns

Climate change, as a result of human activity (primarily fossil fuel energy use which releases carbon dioxide, or CO_2, into the atmosphere), has been observed globally and is projected to become more apparent throughout the next several decades. New York State agriculture is vulnerable to changing climate and market conditions, including:

- Crop responses to changes in regional temperature (frosts & heat waves)

- Variation in seasonal precipitation, including extreme weather events (floods & droughts)
- Distribution and variety of pests and pathogens in response to weather changes
- Increased temperatures affect crop and livestock production (including meat, eggs, dairy)
- Energy price fluctuations as a function of increased regulation of fossil CO_2 emissions

Summary of Regulation of GHG Emissions

While there are regulations on GHG emissions from the electric sector, there are no regulations of GHG emissions from agriculture. Action in this arena continues a tradition of farm stewardship. There are many exciting and pragmatic mechanisms for agriculture and forestry to proactively reduce GHG emissions, and government programs to assist in stewardship.

Goal

This Information Sheet is an introductory overview to help farmers, conservationists, educators, and farm advisors navigate voluntary methods for reducing GHG emissions from a variety of practices across different types of farms. We focus on key opportunities that have substantial co-benefits like improved profitability and yield (summarized below). There is a glossary and six detailed Information Sheets that provide many more opportunities and additional background information (See the "Resources and Tools" section near the end of this document).

A Selection of Potential On-Farm GHG Mitigation Strategies

Description of Strategy	**Opportunities**	**Considerations**
Dairy Feed Management (see Information Sheet #2)	Reduce nitrogen in animal feed to reduce N_2O emissions from manure storage, and improve diet efficiency to reduce total inputs and potentially reduce the enteric emissions of CH_4 from the cow.	Requires animal diet planning and testing of diet and manure.
Manure Storage (see Information Sheets #2 & #3)	Cover, capture, & flare CH_4 produced by anaerobic storage of manure; consider improving livestock diet to reduce precursors for N_2O and CH_4 production.	Cover and flare systems as well as Anaerobic Digester Systems have high capital costs and need maintenance.
Energy Conservation & Efficiency (see Information Sheet #4)	Energy conservation and improved efficiency reduce fossil fuel GHG emissions, and often reduce costs and increase profits.	Improvements may pay for themselves over a few years, but upfront costs may include a professional energy audit, capital & labor costs; some practices may increase energy use to achieve other types of profit & benefit.
N Fertilizer Management (see Information Sheet #5)	Precision N application (of manure and synthetic N) reduces N_2O emissions while maintaining crop yields if timing, source, and rate of application are carefully managed.	Requires careful record-keeping to account for past and current manure application rates, soil N supply potential, cropping history, yields, etc.
Soil Carbon Management (see Information Sheet #6)	Perennial crops, pasture, and forest root systems sequester soil carbon and use nutrients more efficiently than annual crops, reducing GHG emissions. Healthier soils retain more water, a benefit in both drought and flood conditions.	Soil carbon should not be considered permanent storage as it can be lost quickly with tillage, and GHG mitigation benefits are quickly lost if a long-term sod is plowed.
Forest Management (see Information Sheet #7)	Managing a forest sustainably for long-lived timber products and/or bioenergy can reduce GHG emissions by sequestering carbon in the forest, replacing high GHG-emitting concrete and steel with wood and/or replacing fossil fuels with bioenergy.	A forest management plan should be prepared by a professional forester, which costs money and requires management. The plan should be updated every 10 years.

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Information Sheet #1: IN DEPTH

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Target Audience

This information sheet targets educators and technicians helping farmers to plan for environmental quality, business well-being, short-and long-term upgrades and expansions, while considering how a land-manager might integrate GHG mitigation strategies into their operational plan.

Target Greenhouse Gases (GHG): carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O)
Background Questions by Educator to Incorporate GHG Mitigation on Farm

Are you interested in finding opportunities to reduce GHG on your farm?
Are you worried about climate change impacts on your farms operations?
  For example:
    Shifts in weather patterns such as increased extreme rainfall or drought?
    Increased temperatures reducing crop or milk production?
Are you interested in reducing your energy costs?
Do you own forests? Do you have a forest management plan?
Crop farms: Are you interested in no-till, conservation tillage, or cover crops?
    Are you interested in reducing your fertilizer costs?
Dairy farms: Are you interested in increasing your feed efficiency?
    Do you have manure storage? Do you have odor problems? Overflow events?
    Are you now, or in the future, subject to CAFO regulation?
    Do you expect to build or expand a manure storage unit soon?

Introduction to Climate Change and Greenhouse Gases

The Earth's climate is never static, but the term "climate change" means a significant change over decades from one climatic condition to another. During recent decades human-caused (anthropogenic) climate change has occurred much, much faster than previous natural climate changes. Since the beginning of the Industrial Revolution, the large increase in combustion of fossil fuels for energy has greatly increased the concentration of carbon dioxide (CO_2) in the atmosphere.

Carbon dioxide is one of many greenhouse gases (GHG) that allows ultra violet light to pass into the atmosphere, but traps heat radiated back from the earth's surface. They were named greenhouse gases because they work just like a greenhouse, allowing light in and retaining the heat. Greenhouse gases include water vapor, carbon dioxide, methane (CH_4), nitrous oxide (N_2O), halogenated fluorocarbons, ozone, perfluorinated carbons, and hydrofluorocarbons. They come from respiration by living organisms including bacteria and humans, agricultural practices such as manure storage units or volatilization of nitrogen in fields, and industrial processes. Emission of these gases combined accounts for 6,870 million metric tons of CO_2 equivalents, or CO_2e (USEPA, 2016). A CO_2e is the common unit for GHG accounting, see Global Warming Potential (GWP), below.

Different greenhouse gases have different Global Warming Potentials (GWP) – Two factors contribute to the global warming potential: (1) the strength of a greenhouse gas, and (2) its lifetime in the atmosphere. These GWP values are calculated for either 20 years or 100 years, representing the average GWP value over those time periods. The unit of GWP is a "carbon dioxide equivalent" or CO_2e, because the other gases are compared to CO_2. Therefore, over 100 years, the GWP of CO_2 is 1. Methane over 100 years has a GWP value of 34 because it is 34 times more potent than CO_2. Nitrous oxide over 100 years has a GWP value of 298. To convert tons of methane to CO_2e, multiply by 34. To convert tons nitrous oxide to CO_2e multiply by 298.

Global Warming Potential (GWP) of GHG relevant to agriculture

GHG	GWP (20 year time scale)	GWP (100 year time scale)	Source
Carbon Dioxide (CO_2)	1	1	IPCC. AR5
Methane (CH_4)	86	34	IPCC. AR5
Nitrous Oxide (N_2O)	298	298	IPCC. AR5

As GWP are all based on carbon dioxide as the reference standard, after multiplying the quantity of the GHG x GWP, we use the common unit CO_2 equivalents (CO_2e). CO_2e is the currency of greenhouse gas accounting. The pie charts below are based on CO_2e and include all major GHGs.

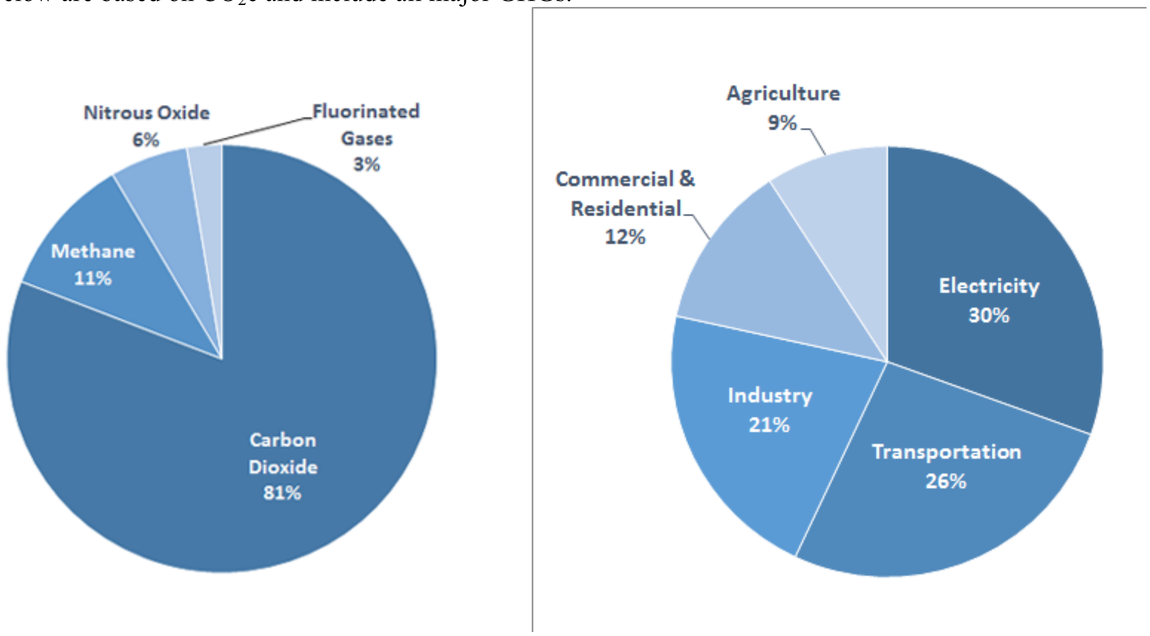

Figure 1: GHG by type and sector (Source: US EPA 2016)

Carbon dioxide contributed 81% of national GHG emissions and is primarily from fossil fuel combustion (USEPA 2016). Agriculture contributed 8.3% of total US GHG emissions. In contrast, land-use, land-change, and forest have functioned as a carbon sink, absorbing 11% of our national emission (USEPA 2016). That is, just as agriculture and forestry can be sources of GHG emissions, they can also sequester carbon, capture and destroy GHGs, and displace high GHG-emitting fossil fuels.

Carbon sequestration means the storage of carbon in a biological or geological sink. Geological sinks include fossil fuels that haven't been mined or artificial sinks such as landfills and processes that inject compressed CO_2 into underground rock bodies.

Biological sinks are soil, trees, wetlands, and the ocean. For carbon sequestration to have a meaningful impact on the atmosphere it is necessary to ensure that the carbon remains sequestered and is not released back into the atmosphere. For example, years of carbon built up and stored in soils can be released back into the atmosphere from just one instance of tillage.

GHG destruction refers to a situation where a greenhouse gas is chemically changed so that it no longer has the same impact on warming the atmosphere. Methane is a common agricultural gas with a Global Warming Potential (GWP) that is 34 times more effective at retaining heat in the atmosphere than carbon dioxide. Combustion of methane (oxidizes CH_4 into $CO_2 + H_2O$), destroys the GWP associated with CH_4. Since CH_4 is an energy source, if this biogas is burned for energy, it can displace fossil fuels.

Fossil fuel displacement means replacing fossil fuels combusted for energy with some kind of renewable energy (solar, wind, biogas) or increasing energy efficiency (avoided emission). Reduction of fossil fuel reduces the amount of CO_2 emitted to the atmosphere from the geological sink.

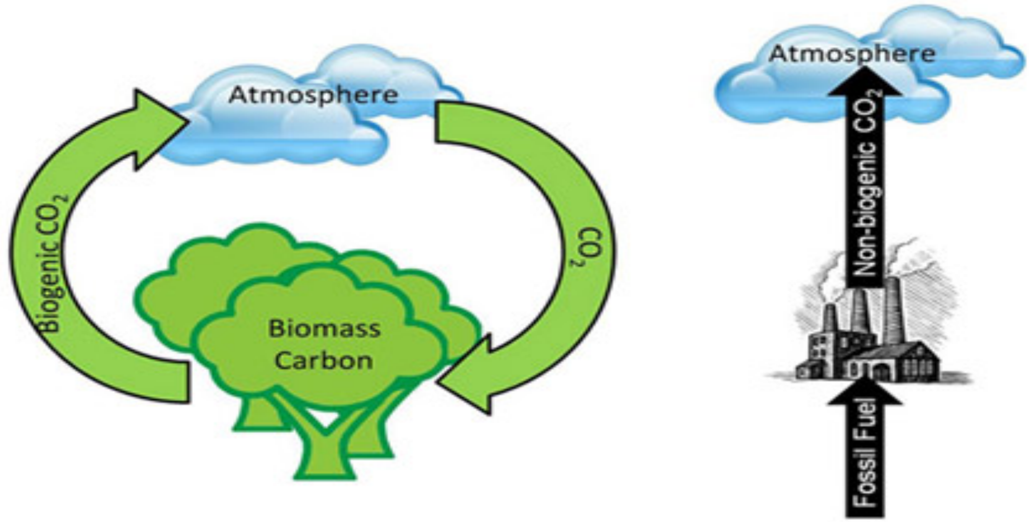

Figure 2: Combustion of biomass for energy recycles surface carbon while combustion of fossil fuels for energy results in a net increase of carbon in the atmosphere (Source: Washington Forest Protection Association).

Concerns

Agriculture and forestry are vulnerable to impacts from our changing climate. These information sheets address mitigation opportunities to reduce GHG emissions that contribute to climate change. These information sheets do not directly address adaptation strategies for land-owners to adapt to a changed climate. Some examples of adaptation challenges for the Northeast USA are as follows (National Climate Assessment 2014):

- Risk of freeze damage from changing temperature patterns during winter and spring.
- Longer growing seasons and warmer winters resulting in new pest and weed pressure.
- Changing temperature and weather patterns reducing crop productivity.
- Extreme rainfall events impacts on infrastructure, erosion, & manure storage overflow.
- Drought requiring installation of irrigation systems.
- Increased temperatures requiring new cooling systems to maintain livestock health and productivity.

Goal

These seven Information Sheets are intended to help landowners identify opportunities to reduce on-farm GHG emission, sequester GHG emitted from other sources off-farm, and identify co-benefits associated from key opportunities for improved farm and forest management.

Sources, Sinks, Displacement, & Destruction of GHG Associated with Forest & Agricultural Practices.

There are four main mechanisms by which land management practices can produce, reduce, sequester, or displace GHG emissions. Many biological processes release GHG and are sources of emissions. Other biological processes absorb GHG, primarily by photosynthesis taking up CO_2 and storing it in plant biomass. The resulting biomass from photosynthesis can be combusted to displace fossil fuels, but fossil fuels also can be displaced by increased energy efficiency or renewable energy systems. Finally, there are practices that capture and convert GHGs into less potent forms, such as capturing and flaring methane from stored manure. By identifying these processes, sinks, displacement, and destruction, we can develop systems to mitigate GHG emissions.

1) **Major sources of farm GHG** come from:

- Enteric CH_4 from cows (burping),

- Manure management practices that release CH_4 and N_2O,
- Poor soil management releasing CO_2,
- Poor forest management releasing CO_2,
- Poor manure or synthetic nitrogen field application releasing N_2O,
- Inefficient energy systems that depend on fossil fuels and emit excess CO_2.

2) **Major sinks of GHG** by good land management:
   - Forests capture CO_2 and store it in tree trunks, branches, and roots,
   - The carbon in forest products can be stored in long-lived wood products such as lumber or furniture.
   - Other perennial plants also capture CO_2 and store it in roots and soil, but this soil carbon can be lost if the soil is tilled.
3) **Displacing GHG emissions** from fossil fuel energy systems and building materials:
   - Renewable energy production such as solar, wind, biomass anaerobic digesters, and hydropower can all displace fossil fuels and reduce GHG emissions.
   - Conservation and efficiency practices on farms can reduce fossil fuel use.
   - Wood products can displace high GHG-emitting building materials such as concrete or steel.
4) **Destruction of methane (CH_4) – a potent GHG:**
   - CH_4 from stored manure can be captured and flared, converting it to CO_2, which is 34 times less potent as a GHG.
   - CH_4 from stored manure can be captured and combusted to generate electricity, both destroying the CH_4 and displacing fossil fuel-based electricity.

The list above indicates there are many ways to mitigate GHG emissions from a farm. The following topics were selected as some of the most meaningful ways for farms and landowners to mitigate GHG emissions with current technology. Each Information Sheet (IS) reviews key concepts and mitigation opportunities for a particular aspect of farm and forest management.

Resources and Tools

To learn more about the opportunities to mitigate GHG on your farm, please see the following Information Sheets (IS):

Resource	Topic	Brief Description
Tier II Work sheet	**Identifying Farm & Forest GHG Opportunities**	While IS#1 (this information sheet) provides a conceptual overview of opportunities to mitigate emissions on farm, the Tier II worksheet provides a matrix for quickly identifying opportunities on farms.
IS1	**Intro to Farm & Forest GHG**	Introduces the basic strategies for climate change and greenhouse gas (GHG) mitigation as it relates to select farm and forest practices.
IS2	**Dairy Manure Storage**	Reviews key considerations for managing the GHG from different manure management systems. Discusses aerobic (high oxygen) versus anaerobic (low oxygen) manure management impacts on methane (CH_4) and nitrous oxide (N_2O) emissions.
IS3	**Planning for Quantitative Methane Capture from Liquid Dairy Manure Storage**	Reviews considerations for installing liquid manure storage units to capture and combust CH_4 with a cover & flare system or capture CH_4 and produce on-farm energy with an Anaerobic Digester System (ADS).
IS4	**Energy Efficiency**	Reviews how energy conservation and efficiency can lead to financial savings while also reducing GHG associated with energy consumption, for example, by improving lights to reduce electric bill or implementing cost-effective ventilation in dairy barns for increased milk productivity in hot summer months.
IS5	**Nitrogen**	Reviews methods of nitrogen management to reduce water pollution,

	Fertilizer Management	GHG emissions and reduce cost for synthetic N-purchase by paying close attention to N-resources in various sources across the farm.
IS6	**Soil Carbon Management**	Reviews different ways farms can increase soil carbon, which improves soil health, crop productivity, water infiltration and retention, and can also sequester carbon in soil. Topics include tillage practices, soil amendments, and annual versus perennial crop options for maximizing soil carbon storage.
IS7	**Forest Management**	Reviews forest management as an under-appreciated method for providing meaningful carbon sequestration with added benefit of carbon stored in long-lived wood products (building materials) after it leaves the forest. That is, by producing timber, carbon may now be stored long-term in building, furniture and other long-lived products. Also covers bioenergy and the benefits of replacing high GHG-emitting concrete and steel with wood products.
Glossary		Terms discussed in all Information Sheets

To learn more about water quality BMPs, http://www.nys-soilandwater.org/aem/techtools.html

References

International Panel on Climate Change (IPCC), Fifth Assessment Report (AR5), 2014. Available at: http://www.ipcc.ch/report/ar5/

National Climate Assessment 2014, US Global Change Research Program "Climate Change Impacts in the United States". Available at: http://nca2014.globalchange.gov/report

USEPA. 2016. Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014. EPA 430-R-16-002, U. S. Environmental Protection Agency, Office of Atmospheric Programs, Washington, D.C., U.S.A. Available at: https://www3.epa.gov/climatechange/ghgemissions/usinventoryreport.html

Washington Forest Protection Association, http://www.wfpa.org/forest-products/biomass/

Credits & Acknowledgments

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This and other Info Sheets available at: http://blogs.cornell.edu/woodbury/