Carbon and Agriculture: Getting Measurable Results

A Report of the Coalition on Agricultural Greenhouse Gases | April 2010

Coalition on Agricultural Greenhouse Gases (C-AGG)

The Coalition on Agricultural Greenhouse Gases (C-AGG) seeks to mitigate climate change and benefit farmers by advancing the development and adoption of science-based policies, methodologies, protocols, and projects for GHG emissions reductions and carbon sequestration within the agricultural sector. C-AGG members are agricultural producers, scientists, GHG quantification experts, carbon investors, policy experts, and GHG project developers.

This report represents contributions from participants in C-AGG and was developed in consideration of the diversity of opinions within the Coalition. It is intended to serve as a catalyst for ongoing discussion, and we anticipate that it will evolve over time as science and data and information improve and evolve. The report is not formally a consensus document, and the specific endorsement of the work as a whole has not been sought from either the participants or their respective organizations.

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Table of Contents

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Connecting People to Solve Problems

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Introduction

The agricultural sector has a pivotal role to play in addressing, mitigating, and helping to adapt to climate change. Despite this, the opportunities for engaging this sector in climate change mitigation have been the subject of extensive debate. There are several reasons for this debate, largely stemming from the underlying importance of agriculture to climate mitigation and the challenge of integrating it into policy approaches.

First, agriculture depends on many diverse biological processes and a great number of equally diverse actors across a variety of managed landscapes. This means that properly addressing agriculture requires a complex and interlinked framework of programs and activities to reduce, sequester, or avoid greenhouse gas (GHG) emissions in a quantifiable manner. Second, programs and activities in the agricultural sector must deal with the issue that biological sequestration of carbon in soils and biomass is at risk of reversal. Third, both GHG emissions and emissions reductions or increased sequestration from agricultural activities are dispersed across large and variable landscapes and can be difficult to measure. Thus, careful consideration must be given in designing appropriate federal, state, and regional climate policies for agriculture to address these complexities while creating a program that both secures broad sectoral participation and maintains environmental integrity. Finally, it is imperative that considerations of GHG emission abatement activities be integrated with other nutrient management issues associated with agricultural resource management. It is increasingly clear that we must deal with these issues in an integrated manner that looks at the range of activities and their nutrient impacts rather than considering them in a nutrient-specific or activity-specific manner. Conversely, incentives to achieve optimal environmental outcomes should consider and reward the many impacts of management activities or practices that have multiple beneficial outcomes.

The agricultural sector has significant potential to remove carbon dioxide (CO2) from the atmosphere and store (or sequester) carbon while at the same time reducing its GHG emissions—in many cases at relatively low cost. With proper policies, the agricultural sector—which currently emits an estimated 6%of annual U.S. GHG emissions[i]—can play a significant role in meeting the U.S. goal of achieving an 80% reduction in GHG emissions by 2050. In doing so, agricultural climate policy can both make an important contribution to the sustainable incomes of farming communities and provide a host of ancillary environmental benefits.

The Basic Science of Agriculture and Greenhouse Gases

Agricultural emissions and sequestration affect three GHGs: carbon dioxide, nitrous oxide (N2O), and methane (CH4) (Figure 1).The basic atoms of these GHGs are carbon and nitrogen. These atoms are also the main building blocks of plants and organic matter. Carbon and nitrogen molecules cycle dynamically between the landscape and the atmosphere through what is known as the carbon and nitrogen cycles. This section provides a brief overview of the main mechanisms related to carbon and nitrogen cycles in order to elucidate the basic GHG-related opportunities within the agricultural sector

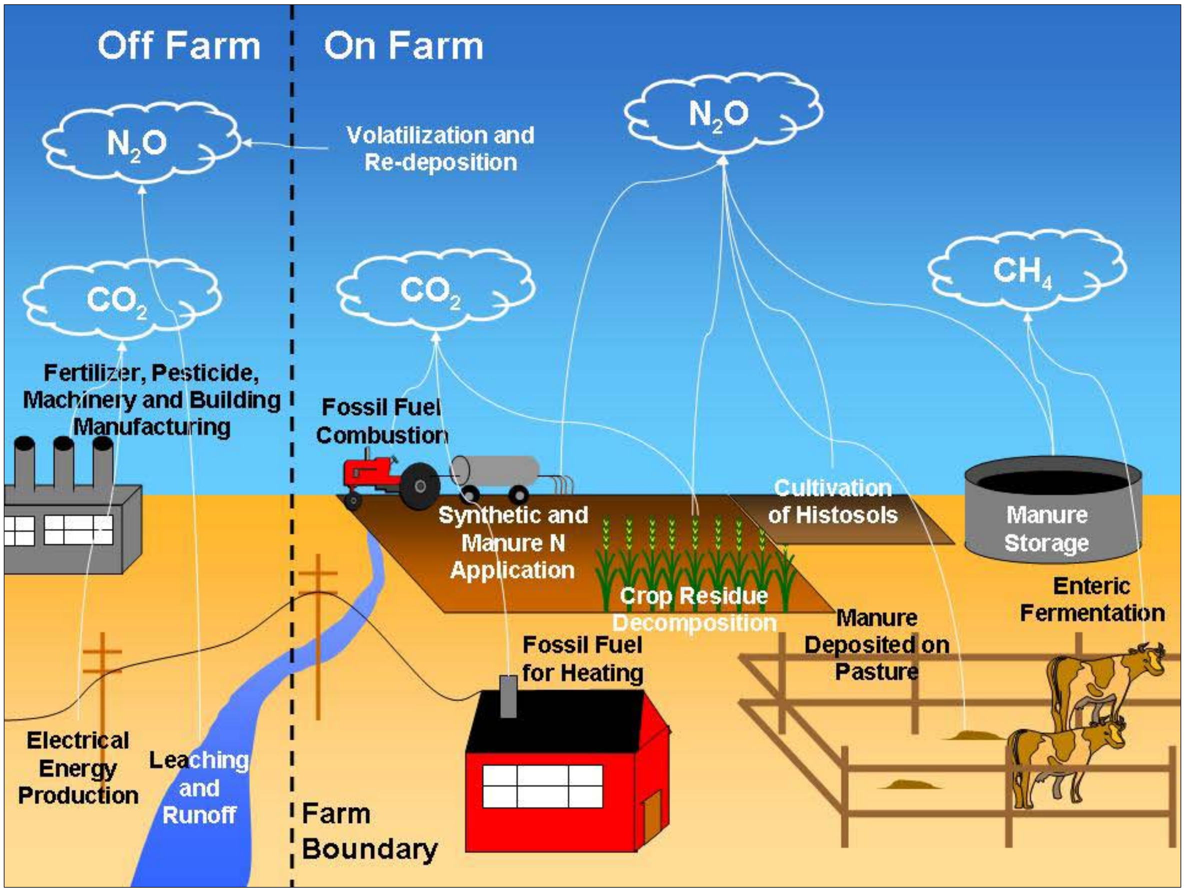

Figure 1. On-farm and Off-farm Emissions of GHGs[ii]

Through photosynthesis, atmospheric CO2 is converted into simple sugars that are further structured into starch and other plant tissues and biomass. When a plant dies, its biomass is partially decomposed and released again to the atmosphere as CO2 and partially converted into soil organic carbon (or humus)—a process known as soil carbon sequestration—by soil microbes and fungi. Historically, large amounts of CO2 have been released from disturbed and deteriorating soils due to burning forests, plowing grasslands, draining wetlands, converting land to annual cropping, and other land use and land use change practices. The loss of soil carbon has decreased soil's structural stability and its crop production potential and has increased soil erosion.

Good agricultural practices can rebuild the carbon stored in the soil that was lost in earlier years by removing CO2 from the air today.

Farmers can sequester soil carbon by reducing soil disturbance through minimal or low-till practices, by producing more biomass by for example planting winter cover crops or adding composts and manures to soils, and by managing crop residues. Every ton of carbon stored in soil directly correlates with a reduction in atmospheric CO2. This carbon sequestration process is seen by many countries, including the United States, as a critical means to reduce atmospheric GHG levels and future emissions of GHGs. Much research has focused on agriculture's role as both a source and a sink—or absorber—of GHGs.

Nitrogen is an essential nutrient for plant growth, but soils that contain an excess of certain forms of nitrogen or receive nitrogen when the plant is not ready to take it up can emit large amounts of N2O through the action of soil microbes. Excess nitrogen in the soil most often occurs through the inappropriate application (e.g., overapplication or application at the wrong time) of inorganic fertilizers and/or excessive manures. Particularly under moist conditions, microorganisms in the soil convert excess mineral nitrogen (in its nitrate form) into N_2O. By synchronizing the amounts and timing of nitrogen fertilizer added to soils with a growing plant's nitrogen demands, and by supplying this nitrogen in slow-release forms, preferably in narrow seed-placed bands, an excess of "free" nitrogen can be avoided, so that N_2O emissions and releases of reactive nitrogen from soils can be minimized.

Methane is primarily produced under anaerobic (oxygen-free) settings such as in water-saturated soil conditions (e.g., rice agriculture) by methanogenic bacteria. In cattle and sheep, methanogenic bacteria also are part of the fermentation process in the rumen. Cattle and sheep thus form the largest source of methane from animal production systems. Conversely, some bacteria present in most (non-waterlogged) cropping systems will transform methane into CO_2, a process called methane oxidation.

Fortunately, much of agriculture is fundamentally about managing ecological landscapes and soils, in a way that "tightens up" the carbon and nitrogen cycles and retains more of these atoms in the production chain rather than releasing them to the atmosphere. Farmers can "grow" soil carbon at the same time that they grow crops and livestock. Practices such as switching from traditional tillage agriculture to a reduced-till or zero-till cropping system (where this year's crop is planted directly into last year's crop residue) not only returns more organic matter to the soil profile (thereby sequestering carbon) and builds soil quality, it also reduces the use of fossil fuels and costly supplemental fertilizer products. Policies that support both GHG reduction benefits (more soil carbon, less CO_2 and N_2O emissions) while supporting traditional farm products will create tangible and globally beneficial results and outcomes. Further, capturing the GHG benefits as a marketable commodity, a carbon offset or credit (see Box 1), will allow the agriculture sector to leverage the broader carbon markets and related pools of investment.

Box 1. Notes on Terminology

Offsets and Carbon Credits

Throughout this document we use the terms "offsets" and "carbon credits" interchangeably. Both terms are used to characterize the GHG emissions reduction benefits from project-based activities. Under a variety of voluntary or regulatory regimes, these units can be used to meet voluntary or compliance-based objectives as a supplement or alternative to reducing emissions yourself.

Carbon Dioxide Equivalents and Global Warming Potential

Each carbon credit or offset is defined in the units of 1 ton of CO_2 equivalent (t CO_2e).Calculation of CO_2e reflects the global warming potential (GWP) of greenhouse gases in which carbon dioxide is used as the reference gas against which other GHGs are measured. For example, one N_2O molecule has the same global warming effect as 298 CO_2 molecules, while one CH_4 molecule has the same global warming impact as 25 CO_2 molecules. This concept makes it possible to compare and rank the impact of agricultural practices on GHGs and global warming and, thus, the mitigation potential of certain activities or changes in practices.

Quality in Agricultural Carbon

In our increasingly hyper-connected world, no issue has become as central to the production of both agricultural and manufactured goods as quality. Quality is what distinguishes products from their competitors, what helps determine both price and access to markets. In a world where money flows instantly from one corner of the planet to another, and where customers have easy access to pricing information at the click of a browser button, quality is the big differentiator.

Even for commodity markets, where quality would seem to be a minor issue, standardized levels of quality are needed to ensure that traders know what they are bidding on and that buyers get what they expect. That is why futures markets define their contracts using terms like yellow corn #1, red winter wheat #1, west Texas Sweet crude, or Brent crude. And just as it is on the Chicago Board of Trade, so too it is for carbon. Because whether we are talking about coffee, corn, or carbon, it is important that commodities be measured, monitored, and standardized. Basic levels of quality are needed if markets are to function. Buyers need to have some assurances that they will get what they pay for.

Every farmer is familiar with the practice of pulling a "test sample" from a bin of stored grain that is ready for market. These tests essentially judge the "quality" of the commodity based on factors such as test weight (the number of pounds per bushel), percent of protein, percent of dockage or foreign material, color, and damage due to disease, frost, or other factors. The market, backed by the U.S. Department of Agriculture (USDA) Grain Inspection Service, has set standardized quality criteria against which all farm products are judged. When it comes to carbon, judging the quality of a carbon credit is both more difficult and more important than it is with standard commodities. It is more difficult because emissions reductions—unlike corn or oil—cannot be seen, touched, and tested. At the same time, it is more important precisely because a carbon credit cannot be physically touched. It needs to be verified and to meet a pre-defined set of quality criteria. A carbon credit is only as good as the standards against which it is verified and measured.

To understand what constitutes quality in the carbon markets, it is useful to understand what constitutes a carbon credit. A GHG offset is derived from a decrease in GHG emissions or an increase in sequestration caused by a project that has met specific eligibility criteria. Over the years, carbon markets around the world have come to expect credible "carbon credits" to meet specific criteria that ensure that a purchased GHG offset actually represents a ton of greenhouse gas removed from the atmosphere. Because of the intangible nature of carbon credits, the criteria and methodologies for GHG reductions revolve around the transparency of accounting and the use of unambiguous standards. Most commonly, the application of these standards are verified by independent, third-party "verifiers." This increases the marketplace's confidence in the GHG offset issuance process and ensures that the quality of the goods being offered, bought, and sold meet the specified quality criteria. Examples of these criteria include:

- Assurances that reduced or sequestered GHGs provide an added benefit beyond regulatory and statutory requirements and are not likely to have happened in the absence of the incentive provided by the carbon market (i.e., emissions reductions result from additional action);
- Confidence that the reduction that occurs has a durable effect over a period of time that is meaningful from the perspective of addressing climate change (i.e., that it is effectively permanent or will remain stored and not be released for an agreed-upon time period and that it has a relevant "lifespan");
- Assurances that the GHG credits accurately represent the quantity of emissions reduced or sequestered (i.e., that they are measurable and quantified to specified standards of accuracy using the best available scientific methods);

- Confidence that the processes and documents that produce, quantify, and track offset credits can be audited by independent third parties and provide additional evidence that the credits are sequestered, reduced, or avoided in a verifiable manner (i.e., sufficient evidence is collected and documented so that buyers and third parties without a conflict of interest can verify the volume of carbon credits issued); and
- Assurances that the outcome of a GHG-reducing activity is not being negated by GHG emissions shifting elsewhere (i.e., there is no leakage, which is typically defined as an increase or decrease in emissions outside an offset project's accounting boundaries as a result of the project that is not otherwise accounted for by the project).

Each of these criteria has over the years played an important role in the development of both regulated and voluntary carbon markets worldwide. These same criteria will have important implications for carbon credits developed through agricultural activities and processes. The difference lies in how agricultural carbon is measured and monitored.

While discussions of verification techniques, additionality, and leakage are necessary when discussing agricultural carbon, the application of these criteria do not differ much in agricultural projects from their application in other sectors. However, measurability and permanence issues become quite challenging with regards to biological systems, including agriculture.

Not only does farmland cover an enormous amount of varied terrain and climates, emissions are highly variable in both space and time. No one single technique has been deemed sufficient to develop a comprehensive GHG measurement or monitoring system for terrestrial ecosystems. This is equally true whether the system in question is an agricultural system or a forest system. At its simplest, this means that carbon sequestered or N2Oand CH4 emissions avoided can either be measured directly using on-the-ground technologies, quantified indirectly through proxy variables or remote sensing techniques, or predicted using biogeochemical process modeling. Each approach and technology has unique constraints related to costs, accuracy or precision, and sampling design requirements. Therefore scientists often use a variety of techniques across a range of scales to crosscheck the measurements from any one method in order to overcome these limitations and to improve the reliability of quantification procedures. Given the centrality of measurement to the development of programs to advance agricultural GHG emissions reductions, Chapter 2 explores the issue in more depth.

Likewise, addressing permanence in agricultural systems can be extremely complex. As molecules move through the nitrogen and carbon cycles, they do not stay in one place. They are in a state of near constant flux. If by permanent we mean "in one place, forever," we are trying to define the actors in a biological process by a measure that simply cannot be adequately applied to highly dynamic living systems. For this reason, the word permanence may be something of a misnomer when it comes to the biological sequestration of GHG. Perhaps a better word for this concept is "longevity" or "lifespan." In other words, we should not be asking ourselves: "Is this carbon permanent?" Rather, we should come to a better definition of the reasonable "lifespan" of a ton (or pool) of carbon reduced or sequestered. As addressing the issue of longevity is vital to moving forward with programs to advance agricultural GHG emissions reductions, Chapter 3 looks at this issue.

There are three additional issues that, while not a focus of this report, need to be at least mentioned here: the rapidly evolving nature of agricultural GHG science and technology, the need for transparency pertaining to all aspects of policy and project development for GHG issues, and the issue of "leakage."

Leakage is defined in the *Special Report on Land Use, Land-Use Change, and Forestry* from the Intergovernmental Panel on Climate Change (IPCC) as: "the unanticipated decrease or increase in greenhouse gas (GHG) benefits outside of the project's accounting boundary as a result of project activities."[iii] Leakage is actually a displacement of emissions or emissions reductions from one area (the project area) to another (outside the project area) that is directly attributable to the project's activities. In the development of forestry projects, leakage has been cited as being a major obstacle,[iv] and there is also a potential for leakage in agricultural projects. All agricultural mitigation interventions must be designed so that there is minimal pressure on other areas. However, the mere occurrence of leakage does not necessarily negate the environmental integrity of agricultural projects. Only in cases where leakage is not quantified and deducted from the project's carbon offsets does leakage pose an insurmountable barrier.

A distinction is made between primary leakage (directly attributable to the actors) and secondary leakage (not directly attributable to the actors), depending on whether the increases in GHG emissions are directly attributable to the actors responsible for the agricultural mitigation activities.[v]

Primary leakage occurs when the actors responsible for agricultural mitigation activities are engaged in new activities that increase GHG emissions outside of the project area due to the planned project activities. It can be further divided into two subtypes:

- **Activity shifting.** Emission reductions are not avoided but merely displaced in whole or in part to an area outside of the project area. This is most likely in cases where yields are reduced. One example is a project area where fertilizer management is implemented but results in lower yields. To compensate for the reduced yields, more fertilizer is used in another area under the same manager who was responsible for the mitigation activities in the project area.
- **Outsourcing.** This occurs when agricultural project activities lead to the purchase or contracting out of the services or commodities that were previously produced inside of the project area to compensate for the loss of revenue from reduced yields. For example, a company that was previously producing rice within the project area purchases rice from other operators to maintain an ongoing supply of rice to their distribution network. This differs from market effects (see below), since outsourcing is undertaken by the original actors responsible for the agricultural mitigation activities and not by third parties.

Secondary leakage occurs when agricultural mitigation project activities create incentives for people other than the original actors responsible for those activities to increase GHG emissions elsewhere. Secondary leakage has market effects when agricultural project activities lead to shifts in supply or demand of the products and services affected by the project actions, which will in turn increase GHG emissions. For example, the reduction in stocking rates due to a rangeland management project leads to a rise in beef prices, which then increase the amount of land under grazing by third parties. However, the difficulty in identifying secondary leakage effects lies in proving the one project had an impact in raising beef prices over all other market and climatic impacts. These will need to be assessed on a case-by-case basis, taking all other drivers into account.

Structure of the Report

To further discourse on these issues, we have produced this document as a "discussion draft" or "Version 1.0," which will be further refined with additional inputs as it serves as a springboard to further discussion and as new science, evidence, and technologies evolve. The report is structured as follows:

- **Chapter 1. Principles:** A set of core principles that C-AGG proposes to guide discussion and policy and program development in the arena of agricultural GHGs.
- **Chapter 2. Carbon and Agriculture: Getting Measurable Results:** A discussion of the "state of the science" and the challenge of obtaining measurable results from projects generating offset credits in changing natural ecosystems.
- **Chapter 3. Permanence:** An examination of the concept of "permanence" and the various tools and mechanisms that have been used—and that could be effectively used—to manage the risk of carbon loss in biological systems.

- **Chapter 4. The Potential of Agricultural Projects and Practices to Reduce GHG Emissions and Promote Carbon Sequestration:** An overview of a sample of agricultural activities that have been identified as having the potential to generate offsets.
- **Chapter 5. C-AGG Policy Recommendations:** Recommendations for the incorporation of agricultural GHG emissions reductions activities into U.S. climate change policies and programs.

The participants of C-AGG believe agriculture has a vital role to play in addressing climate change and helping the United States meet its GHG emissions reduction goals. Furthermore, we are confident that efforts to reduce agricultural GHG emissions and increase soil carbon sequestration can benefit farmers, landowners, and the environment if guided by science and undertaken transparently and with appropriate measurement, monitoring, and verification protocols. This report is intended to provide information useful to those designing policies and programs to realize agriculture's potential contribution to GHG mitigation.

Chapter 1. Principles

The members of the Coalition on Agricultural Greenhouse Gases propose the following guiding principles for designing policies to enable the agricultural sector to participate effectively in the effort to mitigate climate change.

Science-based. The design of agricultural climate policy must be informed by the best available science and should be adaptable over time to integrate improved science.

Quantifiable, Verifiable, and Results-Based. Only quantifiable and verifiable programs and activities that deliver net reductions of atmospheric GHG concentrations should be rewarded.

Larger rewards should be provided to participants who deliver greater results in order to encourage the private sector to reduce atmospheric GHG concentrations at scale and as quickly as possible.

Trade-offs between precision and accuracy of quantification and cost will be necessary but should diminish over time as innovation delivers better technology and lowers costs.

Programs and activities should focus on the result desired (net reductions or removal of GHGs) rather than the means of achieving the result (what practice was implemented). Although systems based on direct measurements are preferred, certain practices have proved to deliver results (i.e., net reductions in atmospheric GHG concentrations) with a high degree of precision and accuracy, and certain models have proved accurate in estimating reductions for particular practices when calibrated using appropriate data.

Leakage of emissions outside of the program or activity boundary that occurs as a result of the program or activity should be accounted for where possible.

Verification of results should occur on a regular basis and be performed by an independent third party.

Innovation. Accelerating innovation is critical to delivering substantial net reductions in atmospheric GHG concentrations.

Many innovators are early actors, and the results delivered by their actions should be recognized.

Additionality. Only net reductions of atmospheric GHG concentrations beyond business as usual should be rewarded.

Permanence. Programs and activities should provide for continued storage of sequestered carbon over timeframes that are meaningful in the context of mitigating climate change.

One way to address the issue of permanence is "risk-based" analysis of the likelihood that a reversal of bsequestered carbon could occur. Different project activities have different factors that increase or decrease the risk of reversals.

Policy should distinguish between intentional and unintentional reversals.

Comprehensive GHG Accounting. A comprehensive accounting should be made of all significant GHGs affected by a program or activity.

Co-benefits. Programs and activities should identify social and non-GHG environmental impacts and take steps to mitigate those impacts where possible.

> *Contributions to social and community well-being, conservation of biodiversity, and improvements to soil, air, and water quality should be encouraged. Activities that increase global food insecurity should be discouraged.*

Bundling Environmental Benefits. Activities that generate multiple environmental benefits that can be clearly identified should potentially qualify for multiple credits or incentives.

> *Where multiple benefits are positive and additional, efforts to separately quantify, verify and value them should be encouraged.*
>
> *Where there are trade-offs between achieving multiple benefits, the programs and activities should seek to optimize the environmental outcome.*
>
> *Multiple benefits should be tracked in a standardized accounting system that provides integrity to the programs and facilitates coordination of multiple funding sources for different environmental benefits.*

Stakeholder Engagement. Stakeholders should be engaged in a transparent, accountable consultation process with program administrators.

> *The consultation process should take account of comments and suggestions from stakeholders in the design of technical standards.*

Chapter 2. Carbon and Agriculture: Getting Measureable Results

Agriculture is a significant contributor to global GHG emissions[vi] and consequently has an important role to play in addressing climate change. Agriculture, forestry, and other land uses contribute 30% or more to global greenhouse gas emissions. In North America, agriculture directly accounts for 6% of GHG emissions and in Canada, 8.5%.[vii]

More important, agriculture has the potential to reduce GHG emissions through long-term storage of carbon in soils and perennial biomass and through reductions of nitrous oxide and methane emissions (Figure 2). In other words, agriculture has a critical role to play in addressing climate change.

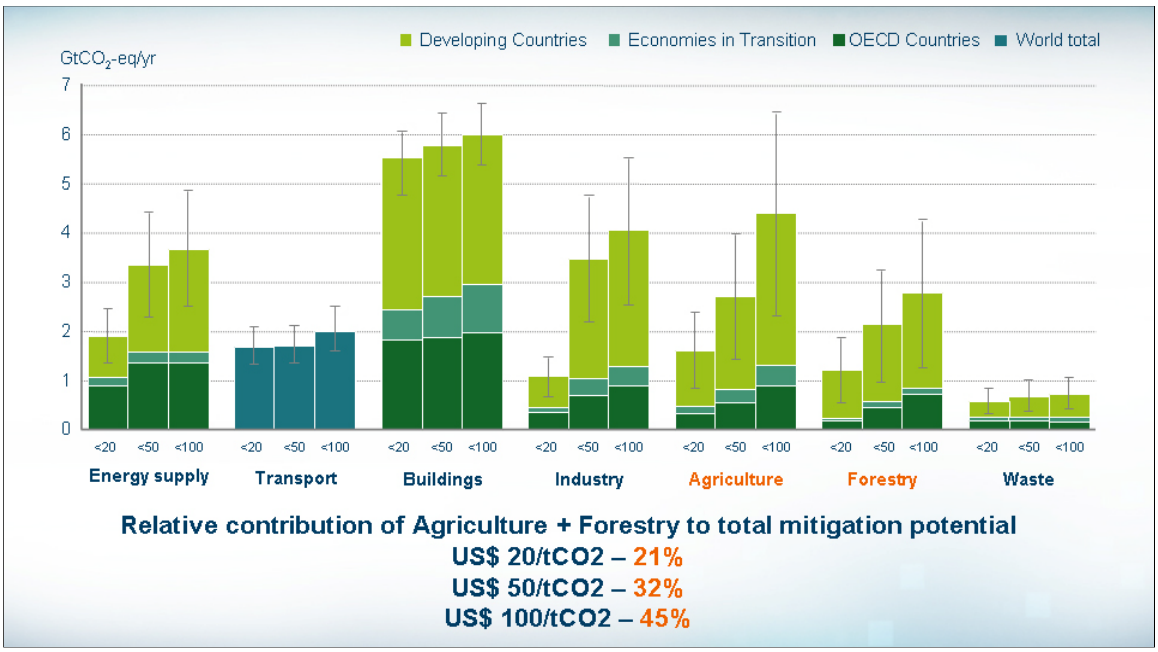

Figure 2. Economic Potential of Various Sectors to Contribute to Climate Change Mitigation (estimated in dollars at market prices per metric ton of carbon dioxide equivalents; percentages reflect potential contribution of agriculture to offsetting the anthropogenic emissions at various market prices)[viii]

If climate change solutions are based on market-based mechanisms aimed at reducing GHGs, participation by the agricultural sector is essential if the maximum environmental benefits are to be realized. In most carbon markets currently in operation, however—including the European Union's Emissions Trading Scheme (EU ETS) and the Clean Development Mechanism (CDM) of the Kyoto Protocol to the United Nations Framework Convention on Climate Change (UNFCCC), and even most global voluntary carbon markets—the inclusion of agricultural offsets has been very limited.

The limited role of agricultural carbon credits within international programs to date can be attributed to several factors. First, carbon markets have historically targeted GHG emissions from large, stationary industrial operations because these sources are (relatively) easier to monitor and regulate than the more complex terrestrial sources of GHGs, which tend to be diffuse and dynamic. While the science of GHG measurement within terrestrial systems is continuously improving, this is an area of science that has not often been shared sufficiently with policy makers. As a result, agriculture has been short-changed in carbon markets.

Second, the full incorporation of agricultural offsets in climate change policies has also been hindered by the complexities of the agricultural sector itself and by the lack of data for many areas of the sector compared with others sources of GHG emissions or sequestration. For instance, a great deal more data and information and (as a result) measurement and verification protocols are currently available on the use of anaerobic methane digesters for livestock than for certain agricultural systems or commodities such as cotton, specialty crops, and other non-broad acre crops. Significant and growing interest in soil carbon sequestration has also led to considerable scientific and policy attention and a proliferation of information on this particular agricultural process. Still, more information on other agricultural activities and processes across the sectoral landscape is needed to fully incorporate the potential for agricultural offsets into climate change mitigation policies that both increase farm income opportunities and effectively remove GHGs from the atmosphere.

As noted in the Introduction, research has demonstrated that in many agricultural settings farmers can "grow" soil carbon without diminishing the production of crops and livestock. Policies that support both of these as marketable commodities will create tangible and globally beneficial results and outcomes.

Many ancillary benefits accrue to farmers and the environment as a result of activities that reduce GHG emissions and increase biological sequestration of carbon on agricultural lands. Most important, soil carbon content is perhaps the best indicator of soil health, fertility, and productivity. Farmers who manage to achieve measurable increases in soil carbon levels generally also benefit from increased yields and water management, while generally improving the efficiency of inputs such as chemical fertilizers, pesticides, and irrigation. Improvements in soil quality also foster increased biological diversity that can reduce soil erosion and water pollution from nutrient runoff, as well as produce a range of other benefits.

Carbon credits therefore provide a unique opportunity to financially reward farmers for beneficial ecosystem services. Properly crafted, market-based mechanisms that create the right market signals can also increase agricultural innovations that can enhance production efficiency and, in many instances, increase productivity as well.

This chapter addresses some of the key questions regarding science-based techniques and technologies used to measure and monitor agricultural projects designed to either sequester carbon or reduce GHG emissions. It touches on a range of issues related to agricultural carbon, including how to ensure that agriculture is able to deliver quality carbon credits, how to develop GHG emissions baselines for agriculture, which pre-treatment conditions should be required, and how to appropriately determine additionality as it relates to agricultural carbon.

The State of the Science of GHG Measurement in Agriculture

Measurement and verification is an essential underpinning to a credible carbon marketplace and to an efficient and effective carbon trading program. This pertains to the agricultural sector as much as to the industrial sector. All relevant and significant avoided GHG emissions and carbon sequestration from agricultural systems will require accurate measurement in order to be credited. In practical terms, this requires knowledge and answers to the following questions:

- What needs to be measured?
- What can be measured, and how accurately?
- How frequent must these measurements be made in order to ensure that the system meets its goals?

These particular questions have been the focus of a number of Methodology Reports published by the IPCC. Thousands of scientists from around the world have reviewed available information and scientific data and have crafted and recommended procedures that lead to consistent approaches in quantifying GHG fluxes. National governments have customized these procedures for country-specific approaches. IPCC guidance has helped identify which management practices reduce GHGs and the kinds of activity data (management and soil-crop-climate) and scientific data needed to quantify GHG emissions reductions associated with these activities. Even though the IPCC reports form a body of research on GHG accounting (even for agricultural practices), most of the techniques described there were developed for national GHG accounting and not for market purposes. Therefore the measurement techniques described by IPCC cannot always be directly translated for use in market-based agricultural carbon projects. However, well-calibrated models are available that can be used to estimate emissions reductions at regional or farm levels.

As noted earlier, measuring or quantifying GHGs from agricultural systems is challenging in comparison to measuring GHGs from stationary industrial processes. Not only does farmland cover an enormous amount of varied terrain and climates, but emissions are highly variable in both space and time. This means that no single technique currently is deemed sufficient as a comprehensive GHG measurement or monitoring system for terrestrial ecosystems. This is equally true whether the system in question is an agricultural system or a forest system. At its simplest, this means that carbon sequestered or nitrous oxide and methane emissions avoided can be measured or estimated in one or more ways:

- Measured directly using on-the-ground technologies,
- Measured indirectly through proxy variables,
- Estimated using remote sensing techniques, or
- Predicted using biogeochemical process modeling.

On its own, each approach and technology has unique constraints related to costs, limitations, and sampling design requirements and thus resulting levels of uncertainty. Scientists must thus use a variety of techniques across a range of scales to crosscheck the measurements from any one method in order to overcome its limitations (Figure 3). Models that integrate and overlay this data can then be used to compile data from diverse measurements in order to scale the estimates of GHG emissions and reductions from measurement sites to fields, entire farms, or even whole regions.

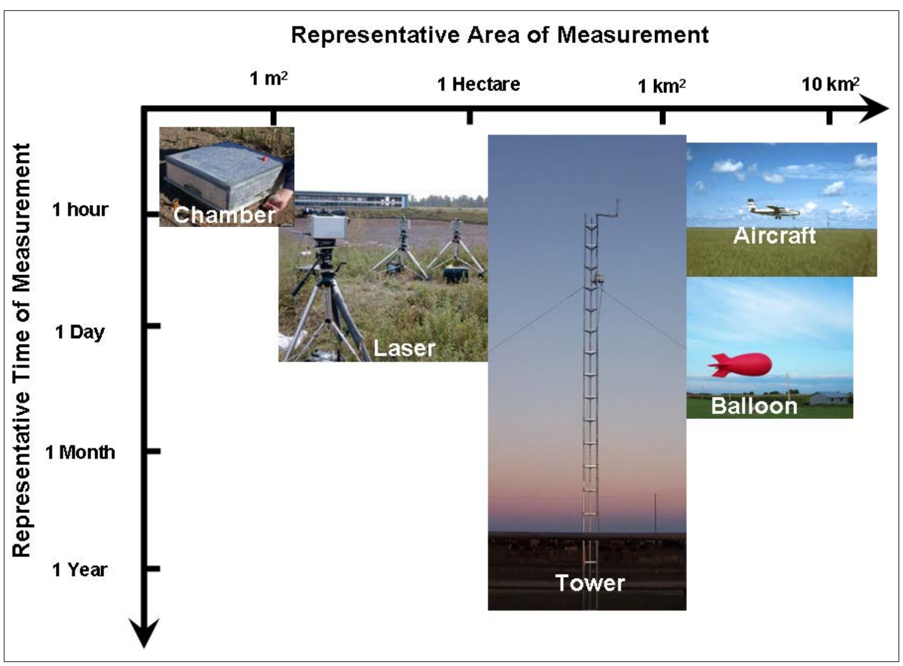

Figure 3. Some Measurement Techniques for Estimating GHG Emissions from Agriculture. Each technique is appropriate over a specific time and area, represented by the size of the photograph [ix]

No single measurement technique will produce perfect results. As in any other industry or technology, all measurements will be associated with some uncertainty due to limitations of the measurement technology itself. (See Box 2 on terminology.) This can include errors introduced by the actual equipment, as well as human error introduced by operating the equipment. But this is not unique to this area of science, and the mere existence of uncertainty does not negate the value of a specific technique or the derived data. What is important is to know the level of uncertainty associated with a particular measurement or estimation technology in order to ascertain the volume of credits that should be awarded based on the use of that technology. After all, if it is uncertain whether an emission has been reduced or sequestered, it is only logical that this uncertainty should be taken into account when awarding credits for the reductions.

Uncertainty can be managed through policy design, such as the use of a discount factor. GHG credits that are measured with a high degree of certainty can be awarded GHG credits that are commensurate with that certainty, and credits with greater uncertainty should receive a proportionately reduced (discounted) amount of credits. Use of a highly uncertain measurement technique would thus potentially yield far fewer credits than a highly certain measurement technique—even if the two were measuring the same activity or agricultural practice, resulting in the same amount of GHGs removed from the atmosphere. Policymakers must determine both minimum acceptable levels of uncertainty and how the level of uncertainty will affect the credits granted. This is, at its heart, a policy judgment rather than a scientific determination, and one where reasonable observers often disagree.

Box 2. Accuracy versus Precision, Error versus Uncertainty

Accuracy. Accuracy refers to the agreement between a measurement and the true or correct value. If a clock strikes 12 when the sun is exactly overhead, the clock is said to be accurate. The measurement of the clock (12) and the phenomena it is meant to measure (the sun located at zenith) are in agreement. Accuracy cannot be discussed meaningfully unless the true value is known or is knowable.

Precision. Precision refers to the repeatability of measurement. It does not require knowledge of the correct or true value. If each day for several years a clock reads exactly 10:17 AM when the sun is at the zenith, this clock is very precise. Note that the complications of edges of time zones do not need to be considered in order to decide that this is a good clock. The true meaning of noon is not important because we only care that the clock is giving a repeatable result.

Error. Error refers to the disagreement between a measurement and the true or accepted value.

Uncertainty. Uncertainty of a measured value is an interval around that value such that any repetition of the measurement will produce a new result that lies within this interval. This uncertainty interval is assigned by the experimenter following established principles of uncertainty estimation. One of the goals of this report is proficiency at assigning and working with uncertainty intervals. Uncertainty, rather than error, is the important term to the working scientist.

Table 1. Overview of Measurement Systems Used to Quantify Carbon Credits in Agricultural Systems

Technique	Variable	Accuracy	Precision	Geographic Scope	Cost
Soil sampling and direct measurements	SOC	*****	***	*	***
Soil sampling and indirect measurements	SOC	****	**	*	**
Terrain-mounted sensors	SOC	***	**	**	***
Hyper-spectral aerial	SOC	**	***	***	****
Multi-spectral satellite	SOC	*	***	*****	**
Biogeochemical process model	SOC, N2O, CH4	*** for SOC, ** for CH4 and N2O	****	***	* once calibrated, **** for calibration
Flux towers	CO2, N2O, CH4	****	***	**	*****
Gas chamber techniques	CO2, N2O, CH4	****	***	*	****

SOC = soil organic carbon

Field Measurements

Chamber methods are widely used for measuring GHG fluxes due to agricultural management practices. Chambers are literally boxes that are placed atop the soil in fields that capture and measure gases emitted from the soil. While chamber measurements are inexpensive and provide good measures of GHG fluxes, the fluxes are measured from small areas within the fields and systems being monitored. Care is needed to extrapolate chamber measurements to the field scale; for this reason, chambers are more suited to measuring relative differences between treatments and not absolute field-scale fluxes. Chamber methods are highly labor-intensive and require continuous sampling and the operation of gas detection devices by trained users. When used to measure GHGs in soils, devices called fixed collars should be used with chambers to minimize disturbance to the soil surface, as these can alter test results by increasing GHG emissions. An additional limitation of chambers is that they cannot be used under water or snow or in tall growing vegetation.

Flux towers and aircraft detect GHG concentrations by measuring air movement to and from the land surface, together with gas detection devices such as lasers and infra-red devices. These techniques take into account the fact that GHGs are emitted at the source (for instance, from soils) and that air moving upward from the soil or other source will contain the greatest concentration of these gases. By measuring the vertical wind speed and GHG concentrations about 20 times per second at a point above a field, scientists can calculate how much GHG is released or absorbed by the field.

GHG emissions are estimated by measuring the difference in gas concentration between two different heights above a field. These relatively new devices are very expensive and require training for accurate use. While they are becoming more commercially available, they are still mostly used within the research realm.

Direct measurement of soil carbon levels is relatively easy, and the soil carbon content can be measured with great precision, but it must be done carefully. This form of measurement involves digging up what is known as "core" samples of soil for transport and testing at a laboratory. The cost for direct measurement is primarily a function of the accuracy desired by the sampling protocol and the variability of the landscape being sampled. Statistically valid sampling protocols need to be used to accurately generalize the sample data to larger areas while retaining precision and accuracy in measurements.

The most challenging aspect of directly measuring soil carbon changes is the design of the sampling and measurement program for each field. Soil characteristics vary greatly both across the landscape and vertically within the soil profile. Further, detecting the incremental increases in soil organic carbon that occur annually against a large background level of carbon stored in the soil already can require many measurements. In order to meet the level of assurance required by most carbon credit programs, and depending on the amount of soil samples that must be taken, direct measurement of soil carbon may not be cost-effective. The scientific sampling protocols will be key to ensuring that the proper number of sampling sites in the same locations year after year is established while also meeting the required assurances in precision and accuracy that the market requires.

Changes in soil carbon content due to plant growth and agronomic practices typically happen at very slow rates per year. Often the annual changes in the soil carbon stock are small compared with the total carbon stock in the relevant soil profile, and they may be below the detectable threshold of the sampling and assessment protocol. For this reason, direct measures of incremental changes in soil carbon content are often taken at multi-year points since it can take up to five years to detect statistically significant changes in the carbon stock. But the main challenge with direct measures is not measuring soil carbon content at a specific location but rather using accurate and cost-efficient sampling methods that take into account variability in soil carbon across individual fields and larger landscapes. Sampling protocols need to take into account soil depth, soil profile depth changes, and changes in the density (bulk density) of the soil in order to reflect changes in soil carbon across the soil volume of the area. Many studies measure to a ~12 inch (30 cm) depth. For conservative sampling, measurements should be taken below any level where a carbon accrual claim is anticipated.

Emissions and uptake of GHGs in agricultural landscapes can be highly variable, both in space and over time. Even within a single agricultural field, major differences can exist in soil carbon content from one particular spot to another. Within a landscape, there are significant differences in micro-climate and soil types, all adding to the complexity of where GHGs are emitted, where carbon is stored, and the net GHG impacts. This spatial heterogeneity also varies from region to region. For example, California has a diverse range of microclimates, soil types and crops, and crops are grown in complex rotation schedules. This makes it especially challenging to extrapolate soil carbon measurements from one part of the state to another. In contrast, mid-western cropping systems, soils, and microclimates tend to be less heterogeneous, hence measurement systems for the Midwest must be designed differently than those for California.

Scientifically rigorous standardized sampling protocols to assess soil carbon content in diverse regions have been designed and used for many years within the soil science community. To provide quality assurances to carbon markets regarding the appropriate use of soil measurement tests and protocols, certain minimal standards and techniques could optimally be required. For instance, the inclusion of "permanent," re-locatable geo-referenced plots can provide repeated time series measurements;

soil testing laboratories can also be required to use international reference samples and standard, calibrated analytical methods when measuring for carbon, N2O, and CH4.A standard laboratory protocol is now part of the quality assurance/quality control requirements in the United States, and participating quality-assured laboratories typically have the technical experience in these measurement-based approaches. Such approaches have allowed the development of well-calibrated and statistically based models for standardizing defensible soil carbon measurements within the scientific community.

Some cutting-edge technologies for carbon measurement and monitoring that are currently being investigated and field-tested include in situ techniques that use lasers or light spectroscopy (the use of light, sound, or particle emissions to study matter).[ix] These so-called rapid measurement technologies do not require "core" sampling of soils to be dug and sent to a laboratory; rather they allow immediate results from the testing of soils in the field by use of handheld or other portable technologies. Some of these tools can be worn as backpacks by a person walking over a field, for instance, while others can be mounted on trailers and literally pulled behind a vehicle and driven over fields. One strength of these technologies is that many of them allow continuous scanning of soils. Thus they can collect a higher number of samples with less labor and in far less time than through the use of core sampling. Each has particular strengths and weaknesses as measurement techniques, so a combination of them should be used to more accurately assess soil carbon and nutrient content.

Some examples of these new systems for soil carbon analysis include the following:

- **Inelastic Neutron Scattering (INS**): This technology directs (nuclear) gamma-rays directly into the soil, which sends a signal back that is immediately interpreted to provide data on the total carbon and nitrogen content of the soil by volume (as opposed to depth). It is a rapid, non-invasive and non-destructive technique that can be used by mounting a portable device on a trailer or platform pulled behind a tractor or it can be used from a stationary platform.
- **Laser-induced Breakdown Spectroscopy (LIBS):** LIBS is a rapid, "person-portable" technology that can be used in the field. The technology focuses a single laser beam on a pressed soil sample that has been taken from the field, and the laser sends back information on the carbon content of the soil sample, which is immediately measured and recorded.
- **Mid Infra-Red Spectroscopy (MIR):** This is a rapid test method that irradiates soil samples with mid-infrared light and collects the reflected radiation to measure soil carbon content. MIR can be used from a portable platform in the field and in scanning mode. This technology can provide good-quality prediction of soil properties, including carbon and nitrogen, cation exchange capacity, pH, soil texture, and some other important soil properties.
- **Near-infrared Spectroscopy (NIR):** NIR is an in-situ technique that beams near-infrared light into soil, where it is absorbed by molecular vibrations that are recorded and measured. NIR instruments can be affixed directly on tillage equipment, which makes it a portable technology. NIR is a similar approach to MIR, but it uses a shorter wavelength ban. One drawback of NIR is that it is insensitive to quartz, a major component of most soils; on the other hand, it copes better with moist soil samples than MIR and can deal with larger bulk soil samples due to more sensitive detectors.

In summary, many credible, rigorous, scientifically valid techniques and protocols to accurately measure and monitor soil carbon content and changes in content over time already exist, and many others are being developed. The challenge will be integrating and commercializing these technologies with rigorous soil sampling and measurement protocols in the future as they become more mainstream and cost-effective. As more technologies and additional science becomes available, new methodologies will likely be added.

Empirical and Process-based Models

Scientists also use modeling and correlations to develop a more comprehensive understanding and accounting of system changes and dynamics. Models can scale up point measurements to the farm scale or even entire landscapes. Models can enable an ecosystem view of GHG emissions, incorporating multiple variables into the quantification, pushing the boundaries of measurement beyond the simple plot or farm scale. Existing models vary in complexity and are built in two basic ways: empirical models and process-based or mechanistic models. Both are in use today to monitor soil GHG emissions and sequestration.

Empirical models use field measurements to develop statistical relationships between soil carbon levels and agricultural management factors.[x] Process-based (or mechanistic) models link important biogeochemical processes that control the production, consumption, and emission of GHGs. One advantage of biogeochemical models compared with empirical ones is that calibration is not necessary each time the model is used (unless it is being used in a new agro-climate regime for which it was not previously calibrated). Over time, models have provided and will continue to provide data that are more robust. This is because as more soil GHG measurements are taken, and as further research is done and additional data are incorporated into models, models more accurately estimate real changes in GHG emissions and sequestration—and thus net GHG emissions.

The development of GHG models typically occurs alongside experimental measurements. Initially, GHG emission measurements give scientists the knowledge they need to create a GHG model. When the model is used or applied under conditions that are different from those under which it was originally designed or applied, new research needs may be identified. To validate a model, it should be tested with different GHG measurements than those used in its development. This process of testing models with new data helps improve the models and to overcome limitations inherent in their original design, based on limited data. Models can be updated to incorporate new system synergies or unexpected practices or results and to match new discoveries. Therefore model development is an iterative process (Figure 4).

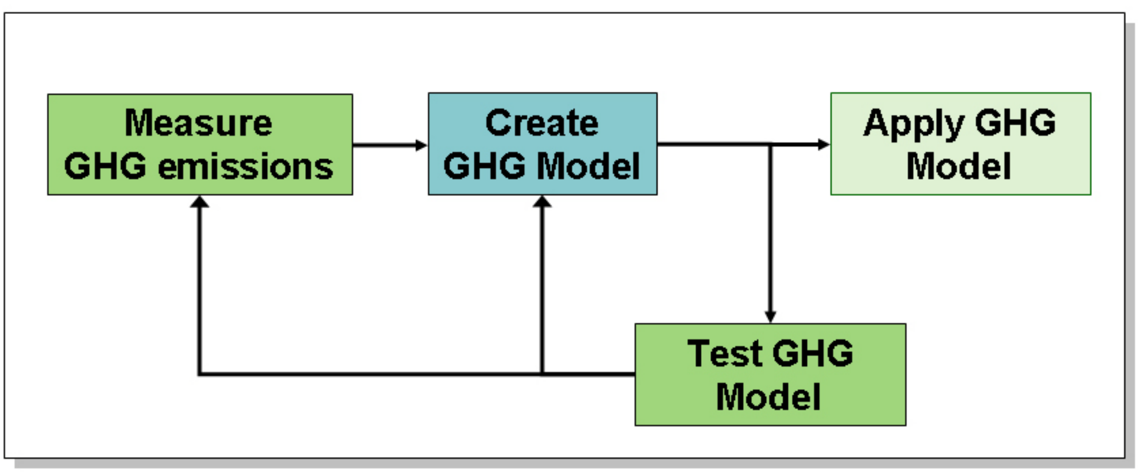

Figure 4.Developing Models—An Iterative Process

Process-based models can be combined or integrated with remote sensing in order to produce more accurate estimates of greenhouse gas fluxes. An example of this is the NASA-CASA (Carnegie-Ames-Stanford Approach) model. In addition, models can be made accessible over the Web to provide decision-support tools to individual farmers regarding the nutrient and GHG impacts of their practices and activities and to demonstrate how possible changes in practices or activities can change or improve these impacts. Examples of the latter are the COMET-VR (The Voluntary Reporting of Greenhouse Gases–Carbon Management Evaluation Tool), CQuest, NUGGET-DNDC (De-nitrification and De-composition), and Nutrient Trading Tool systems. These may be coupled with existing geographic information system (GIS) databases (e.g., on soils and weather) for site and watershed-scale analyses.

Some methodologies, such as the use of remote sensing, are being developed for specific applications. Remotely sensed data are well suited to measuring and monitoring grassland grazing management because changes in above-ground biomass from grazing are easily detected via remote sensing. Altering grassland management is a potentially important tool for sequestering atmospheric carbon in soils. Unfortunately, information about grassland management, rangeland condition, or rangeland deterioration has been quantified only using large-scale surveys. These data are useful as a first approximation of land management change at any particular location, but changes are not discernible directly, and net rather than gross change is typically evaluated.

Remotely sensed land use and management activity data offer many potential benefits for measuring terrestrial carbon: they are spatially explicit, broad in extent, uniform for the entire area sampled, repeatable over time, and capable of appraising the entire landscape, and they allow incorporation of more detailed information into regional analyses of carbon dynamics.

For carbon trading schemes, calibration and validation of measurement technologies and processes will be required. In addition, validation methodologies for carbon trading must address systematic uncertainty and confidence levels. The cost of calibrating and verifying models with ground-based measurements is beyond the reach of individual farmers and is usually more costly than the potential income stream from selling carbon credits for the average U.S. farm (around 400 acres). Ideally, the cost of calibration and verification would be shared by aggregating groups of farms in a certain region or by belonging to a certain group or cooperative. A network of collaborators could regularly calibrate and verify at permanent sampling locations. These locations would effectively be long-term studies and provide data sets that document long-term effects of alternative cropping practices.

For regional applications, models require input data on several environmental factors, such as meteorological conditions, soil conditions (e.g., type, organic matter, texture), and topography. They also require inputs on farm management activities, and how all factors vary over time for a site and region. In the United States, high-quality spatial data are generally available for meteorology, soil conditions, and topography from remote sensing. GIS-based information systems are also improving the organization and collection of activity data for use in models. But land use and management activity data are less available at the regional level and need to be improved in order for model-based regional estimates of GHG reductions to be used to support market-based measurements.

Several types of data are sorely lacking at this time, including soil carbon time series accrual data that document changes in soil stratography, levels of total carbon, soil organic carbon, and soil inorganic carbon.

The USDA, the U.S. Environmental Protection Agency (EPA), and many research institutions have accumulated a wealth of measured emission and sequestration data that are not currently accessible or available in an aggregated form. As a very early step, agencies should organize a national pooling of these data from past public investments to more quickly build, calibrate, and refine robust models. Well-organized geographic databases should also be created for stakeholders to use in developing performance-measurement-based carbon projects.

While models can be very useful and informative, they do have limitations. For example, if a given farmer or set of farmers use farm management activities unlike those included in the construction of the model, the model runs into its limits, and further inputs or measurements are necessary to calibrate the model and quantify uncertainties in model estimates for these "new" activities. Further, the complexity of some models requires advanced training in order to run them accurately and consistently. In most existing project applications, models are applied at small scales in diverse systems and then "scaled up" using GIS or spatial statistics to understand regional dynamics and impacts. In addition to uncertainties from model structure, the aggregation process leads to other uncertainties due to model limitations inherent in scaling up. At this time, however, models represent the most viable way of including methane and nitrous oxide in agricultural projects.

Integrating Direct Measurements with Process Models to Cost-Effectively Quantify Carbon Reductions in Agriculture

As noted earlier, the participation of agricultural projects in emerging carbon markets will be intricately tied to the various ways that the GHG flows from agricultural landscapes are measured, monitored, and understood. Such a relationship is not unique to agricultural landscapes. The same issues have in fact dominated discussions of forestry carbon and other forms of carbon sequestration projects. As discussions evolve around techniques to mechanically capture and sequester carbon geologically (now known as carbon capture and sequestration, or CCS), these same issues will emerge.

Essentially, the problem revolves around that fact that uncertainty in GHG measurements is generally inversely related to the cost of deploying measures (Figure 5).

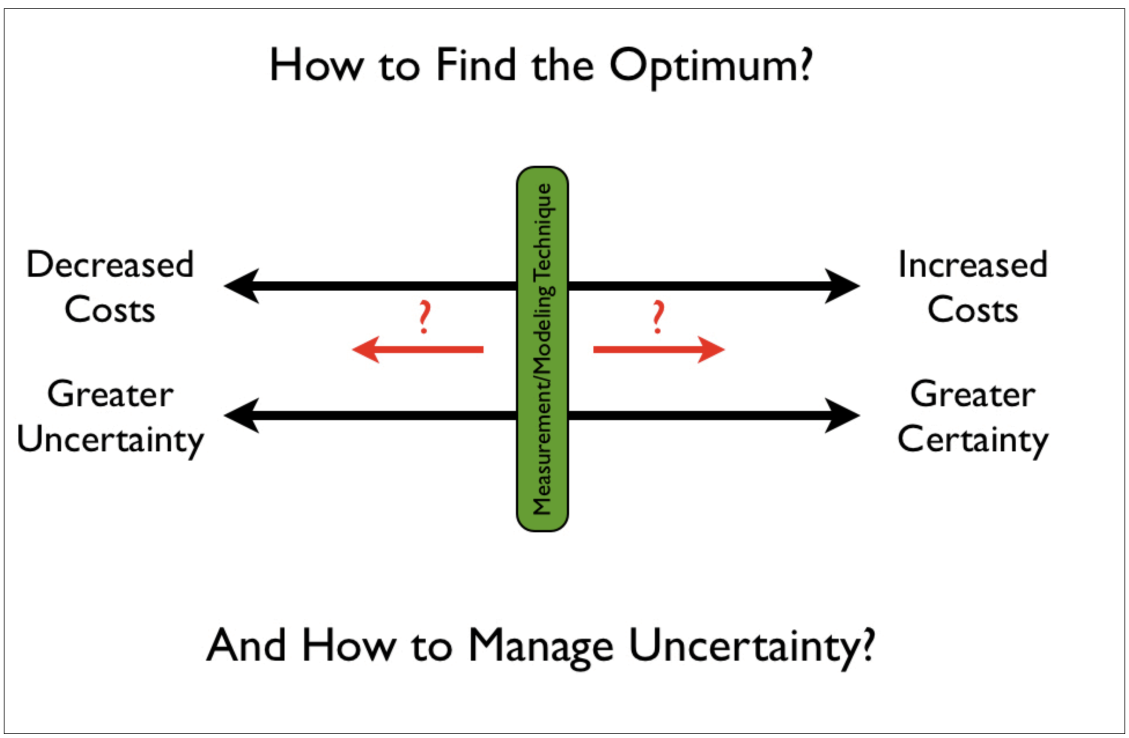

Figure 5. Relationship of Cost to Uncertainty in GHG Measurements

Naturally, this relationship is not necessarily as linear as the Figure suggests. There are likely ways where a small increase in costs can lead to much greater certainty or even cases where greater certainty can be achieved at little or no cost. Still, for the vast majority of projects, achieving greater certainty will almost always imply greater costs. This means that there are several approaches and trade-offs to be managed.

First of all, it is important to get a handle on the level of uncertainty. For any given project, it is important to know (or at least have a sense) of how certain or uncertain its results are. If the relevant levels of uncertainty can be determined, they can be managed. Second, a decision must be made about the level of certainty required. And how much are we willing to spend (as both a society and a project developer) to achieve greater levels of certainty? In the end, these policy decisions will be informed by science, but they require considered judgment calls by those writing the standards.

Once the acceptable level of uncertainty has been determined, the next question becomes, How do we manage the remaining uncertainty? All forms of measurement and modeling carry some level of uncertainty, whether it be the precision limits of the measuring instruments, human-induced error, or something more fundamental such as the natural variability of carbon within biological elements. This means that even in the most "scientific" approaches to measuring soil carbon there will still be some level of uncertainty, particularly when these measurements are extrapolated. Further, the need to estimate the net effect of all three GHGs in agricultural projects, not only soil carbon, means that we must live with uncertainty for some time to come. Ironically, for some forms of measurement or modeling, measurements of GHG emissions or sequestration may actually become more certain as they are applied across larger landscapes. This is because the factors that contribute to a higher variance may result from site-specific farm management effects, which become statistically less influential when more farms are included in the analysis over a larger landscape. Still, the point is that there will always be some level of uncertainty associated with quantification of any GHG emissions reduction or sequestration project. The key is knowing how to usefully estimate uncertainty and manage it.

One way of managing uncertainty is to apply discounts based on the level of uncertainty. Such an application of discounts tied to levels of uncertainty can significantly enhance the probabilities that at least a ton of CO2 emission was reduced when a credit is issued; however, these discounts also increase the costs of providing each ton of verified credit and potentially reduce the profit margin of such projects. While discounting can be useful, it can also work against the goal of providing adequate incentives for the farming community to shift toward low-emission/high-sequestration practices. Thus, measurement system costs must be weighed against the loss of revenues or profits from discounting.

Measurement costs at whole-farm scales present challenges that are best met by integrating direct measurement with process models in order to achieve the least amount of uncertainty at the lowest possible cost, particularly when considering non-CO2 trace gases. As measurement costs decrease over time due to technological advances, experience, and improved data, smaller-scale and more diverse farm operations are more likely to benefit from direct measurement strategies.

In the short term, sufficiently calibrated model-based estimates of carbon reduction performance linked to agricultural activities can be used in carbon markets, particularly if these are combined with direct sampling or measurements. Direct measurements are necessary to define uncertainty levels and apply appropriate discounts. Sampling should be used to ensure accurate estimates of baselines and GHG emissions reductions. Methodologies are needed to properly integrate modeling and field measurements for use in carbon markets, and they should define quantification protocols to ensure they are applied properly.

As on-farm measurement technologies and techniques evolve, the costs of these methods will drop, and as their use in carbon markets becomes more practical, farm- and field-level sampling will increasingly be used in carbon credit projects. This will give farmers and carbon project developers an opportunity to more accurately assess the range of uncertainty and discounting on a particular project. If policies allow, some may choose to use measurement processes that reduce uncertainty, resulting in less discounting and the award of more carbon credits. Others may find it less onerous and expensive to use less accurate measurement techniques, and they may simply choose to accept greater uncertainty and the higher level of discounting that comes with it.

This potential two-tiered approach to measuring GHGs in agriculture is illustrated in the Performance Continuum concept (Figure 6). Ideally, new policies or programs to encourage GHG emissions reductions would include incentives to stimulate innovation and to drive investments in more-accurate measurement technologies. The result will be reduced uncertainty, increased value, environmental integrity, and the delivery of ecosystem services that combat climate change and restore Earth's soils.

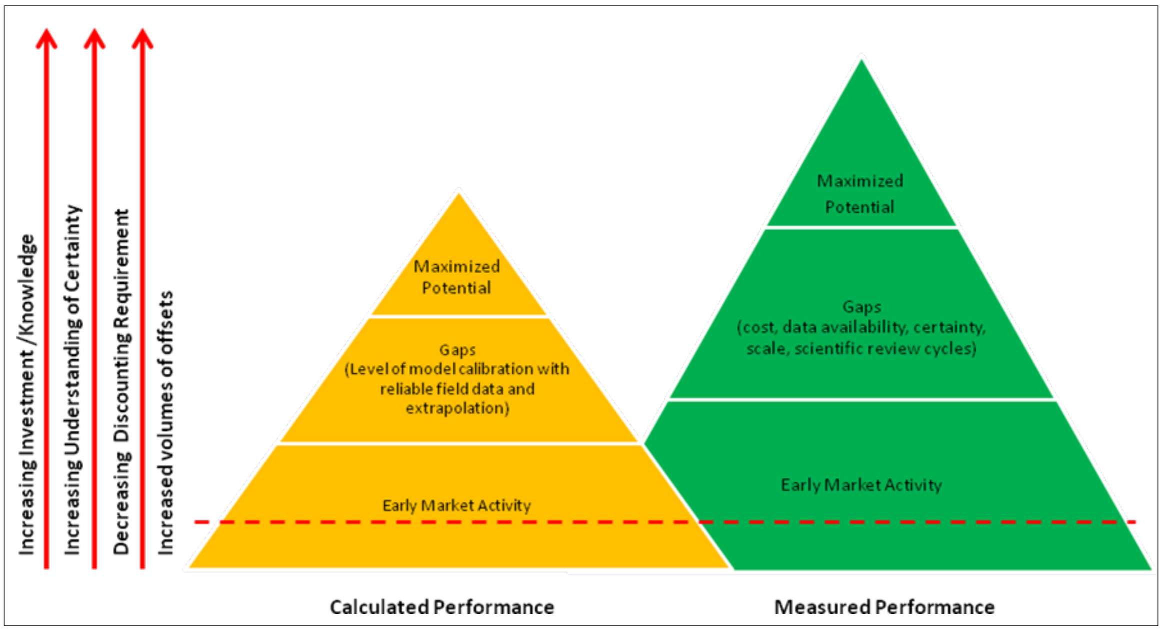

Figure 6. Performance Continuum. A measurement continuum exists from model-based estimates (calculated performance) to a system using direct measurements of agricultural management changes, and the marketplace should incentivize this shift to measured performance.

The first tier, to correlate measured on-the-ground performance to specified land management practices, would use calibrated and extrapolated models developed and tested across agricultural regions. Methodologies are needed to link these models with valid baselines and practices that lead to GHG reductions and increases in soil carbon sequestration. These methodologies are needed at the farm scale and at larger aggregated scales, over many aggregated farms, perhaps even over watersheds and regions. Ultimately, they also need to link to the standardized quantification protocols being developed now at the project level to quantify carbon credits.

As the science continues to evolve, reliance on the integrated use of direct measurement of performance at field, farm, and regional scales, together with calibrated models, remote sensing, and GIS applications, can synthesize the various scales of available data to make standardized project-level projections. Field sampling systems can continue to produce data to feed into the models at the project level, which will increase the robustness and validation of these models, thus reducing uncertainty over time.

The right policies and incentives can drive continued investment and innovation in measurement technologies that increase certainty, reduce discounting, and ultimately result in more marketable carbon credits and financial returns to the agricultural sector—all while achieving GHG emissions reductions and ensuring the environmental integrity of the GHG mitigation program.

Conclusion: Key Agriculture and Carbon Policy Issues

The agricultural sector should be included from the start in future GHG carbon offset trading systems for a number of important scientific, economic, and political reasons. Whether agriculture can meaningfully participate, however—and to what extent—will depend on the design of carbon crediting systems and the recognition of agriculture's unique role as a source of GHG emissions reductions as well as its ability to sequester carbon and reduce GHGs—all while providing society with food and fiber. The goal of measured results, using the outlined tiered system of models to measurement, sets a practical pathway to engage agricultural producers immediately, linking performance to credible measurement and crediting systems that work for agriculture while building incentives and investments to improve measurement systems for tomorrow.

Performance-based crediting systems meet the criteria established at the beginning of this chapter. They form the basis of carbon markets that can capture the potential value for agriculture because performance and measurement-based systems:

- Allow farmers and ranchers the greatest latitude in how they use their resources and manage their land while producing food and fiber, unleashing the practical innovation and creativity of farmers, and
- Provide critical assurances to the marketplace and to investors and buyers of carbon credits that the commodity they are paying for exists, can be verified, and will deliver real, measurable credits and environmental benefits.

Initially, the marketplace will determine where it is possible to use performance-based approaches, and where it is not. The role of regulations and the marketplace should be to create incentives that foster performance/measurement-based approaches that are economically feasible and practical at a variety of scales, including at the farm scale, across aggregated farms, and at watershed and regional scales. This approach should provide incentives for collaboration between farmers, farm organizations, governments, investors, and philanthropists to ensure that adequate resources are invested to continuously improve techniques for measuring, modeling, and understanding the flux of GHGs from agricultural landscapes. In particular, the problem of how to reliably measure and understand fluxes of N2O from agricultural landscapes and CH4 from manure and livestock can and must be addressed in order to fully tap the benefits of agricultural offset credits.

This strategy has important implications for policymakers. First, the design of carbon reduction and trading regimes should include incentives for agricultural offsets to be generated, with clear preference given to GHG emissions or sequestration activities that can be reliably measured.

Second, it is important that the trading system design focus on understanding where and when performance-based crediting systems are viable, and where they are not currently economic or technically feasible. Where possible, measurement methodologies need to be established in close consultation with scientists, agricultural producers, and financiers. Just as important, where they are not presently thought to be viable, financial incentives should be used to leverage economic and technological breakthroughs, to ensure it becomes possible to improve methods for monitoring and measurement.

Third, governments should work closely with agricultural producers in order to use carbon trading programs as a way of unleashing their creativity and innovation. Ultimately, farmers must determine the best ways to make their farm produce better results, whether with an improved corn crop or increased carbon sequestration, or both. Using performance and measurement-based crediting will unleash creativity and innovation.

Fourth, the restoration of soil carbon levels and reduced GHG emissions from agricultural landscapes (cropland, rangelands, grasslands, wetlands, etc.) can take place immediately at low relative cost and with high environmental benefits to society.

Fifth, carbon crediting baselines need to be established at the start of projects so that credits are generated only from the incremental addition of carbon to the soil or reduced GHGs. In this context, incentives to maintain existing carbon stocks will likely be as important as incentives to build new ones.

Sixth, the use of integrated measurement and modeling techniques to credit emissions reductions as well as increased sequestration and carbon storage in soil sinks should be developed. Scientists, technicians, agricultural producers, the federal government, and other stakeholders interested in the role of agriculture in climate change mitigation policies should invest now in an extensive and comprehensive effort at model validation to develop quantifiable model uncertainties and confidence levels and to identify current gaps in model performance.

Chapter 3. Permanence

If land-based credits or offsets are to be fully fungible, certain quality assessments must be undertaken and buyer assurances must be made. Offset project methodology and offset accounting principles must meet tests of additionality and leakage, and the results must be measurable, verifiable, and durable. This question of durability or “permanence” is especially complicated when the offset projects involve complicated biological systems influenced by natural events and managed by a set of diverse and sometimes changing individual actors. It is possible, however, to ensure that the environmental benefits of agricultural offset projects will have a lasting effect. This chapter explores the concept of permanence, identifies risks to durability, and discusses some mechanisms to handle these risks.

Definition of Permanence

For carbon sequestration projects, “permanence” refers to the amount of time that the carbon removed from the atmosphere will remain out of the atmosphere. If an offset is to be recognized for removing carbon from the atmosphere, it should have the same impact on atmospheric concentrations of greenhouse gases as an avoided emission. Critics have expressed concern that carbon sequestered in vegetation or soils can be re-emitted to the atmosphere at any time and therefore should not be recognized as an equivalent offset. However, soils and vegetation have been significant sources of increased concentrations of greenhouse gases in the atmosphere, and providing incentives to avoid further emissions from them and to restore carbon stocks in vegetation and soils can produce real benefits to the atmosphere.

In practice, “permanence” is defined differently under different market mechanisms, and the issue of who is liable for ensuring continued sequestration is not a simple one (see Box 3). The market created under the Clean Development Mechanism (CDM) says that increases in carbon sequestered in trees from afforestation or reforestation can only be considered temporary and are not fungible with avoided emissions. Some voluntary markets seek to define “permanence” as a finite number of years and to require that legally binding contracts ensure that any future owners of land commit to maintaining carbon stocks in vegetation and soils for that defined period. For these markets, the question is, What is an appropriate timescale? Other markets recognize that carbon can remain sequestered in products or dead wood pools even if it is removed from the land. For these markets, the question is, How to track stored carbon as it moves offsite, and for how long? Still other markets define “permanence” of an offset as managing risk to ensure the amount of carbon transacted as an offset remains out of the atmosphere. These markets are most concerned about assessing the risk of loss over a portfolio and about the duration of commitments because that affects the structure of insurance products. Ultimately, the terms under which offset trading will be allowed for carbon sequestered in soils and vegetation will depend on policy decisions.

Box 3. Who's Liable? A Market Perspective, by Ricardo Bayon

Who should be held liable—legally and financially—for ensuring that a ton of carbon sequestered today remains sequestered tomorrow, in 30 years, in 100 years, or in 1,000 years? At the most simplistic level, we can argue that whoever uses a sequestered ton to offset their emissions should, in theory, remain liable for the "permanence" of that ton, but this may not be the best way to achieve our climate change goals. In fact, such a simplistic solution may in some cases work against our long-term goals.

To give but one example: When we create carbon markets (or any other environmental markets for that matter), we have two broad overarching goals in mind. The first, and perhaps most important, is to create a system whereby we begin to put a price on the emission of a ton of carbon. This is the sharp point of the carbon market spear, the main and perhaps most important reason for creating a carbon market, the way we achieve the "polluter pays" principle. Achieving this goal, however, is only marginally influenced by any decisions on the definition of permanence. Sure, greater numbers of cheaper offsets will influence the price that emitters have to pay for each ton of emission, and stricter rules on permanence will lead to higher offset prices, but most carbon markets rely on offsets only for a small portion of the tons that are traded. In other words, the relative impact on the price of carbon of a change in the price of a ton of offsets will depend more on how (and how many) offsets are allowed into the trading regime than on any changes to the definitions of "permanence" or carbon lifespan in the system.

Beyond putting a price on each emission of carbon (punishing the "bad"), the second avowed goal of a carbon trading market is to bring money and investment into things we want to see happen (i.e., rewarding the "good"). A well-designed offset market can play a key role in this case. By encouraging private investment and speculation, the offset system can channel capital toward activities that we believe are important in addressing climate change. This is especially true in a system where not all emitting sectors fall under the cap.

Here, the concept of permanence—how we define the "lifespan" of a ton of carbon and who is deemed financially and legally liable for that ton—can have a relatively big impact. For private investors, whose concept of return on investment is measured in months and years, not decades, entering into a contract with liabilities that are measured in centuries can be a non-starter. Even for farmers and landowners who do measure their returns in decades, the concept of signing agreements that encumber their lands for centuries can often be a deal-breaker. This means that if we define "carbon lifespan" in a way that doesn't make market or financial sense, we may be inadvertently hampering our ability to bring capital into activities that we all agree can help us address the climate change problem. Surely, there is a better way.

One way of addressing this problem may in fact be to separate the concepts of "carbon lifespan" and liability. For instance, we can imagine a system whereby we agree that carbon should remain sequestered for 50 or even 100 years, but we deem that carbon investors (and landowners) are only liable for a portion of that lifespan. We could then rely on government to create a fund that would cover the balance of liability. We can look at it as a system-wide buffer, or a government-backed insurance scheme (tools that, despite recent setbacks and bad press, have been used to great effect in the past—think of how the government encouraged homeownership using FannieMae). And we could even charge a fee on each carbon transaction to fund the system. Another way to bring money into such a fund could be to impose a fee on each offset bought since, after all, it is the really the buyers of the offsets that should ultimately be "liable" for the longevity of this carbon. It is, in effect, their liability that this fund would be covering.

To summarize, the concept of permanence (or carbon lifespan) is indeed central to any discussion of carbon sequestration, regardless of whether this sequestration comes in the form of forestry projects, agricultural projects, or carbon capture and sequestration. But lifespan and liability—though related—do not always have to be the same thing. Indeed, by distinguishing between these two concepts, we may be able to design carbon markets that better meet our needs and address our problems.

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Carbon offset projects that sequester, store, or preserve carbon stocks in trees, other vegetation, and soils face the risk of future events, such as fire, disease, or human intervention, causing a loss of carbon to the atmosphere. Such a loss may alter the average carbon stocks during any particular time period and require changes in carbon credits recognized during this time. Carbon losses due to fire, disease, and other natural events may only produce relatively short-lived reductions in carbon stocks that could be made up in subsequent periods and are not of sufficient size and duration to be labeled a "reversal" in all cases. Average carbon stocks on landscapes can be maintained over long periods of time despite periodic carbon losses. Some events can alter the fundamental characteristics of terrestrial sequestration projects, resulting in a reversal.

The environmental integrity of any carbon regulatory system, standard, or protocol requires mechanisms to address permanence. A number of approaches have been developed in voluntary and regulatory carbon markets to ensure adjustments are made to account for potential loss of carbon from forestry and agriculture projects. The potential for carbon loss or reversals is not a sound reason to exclude potential terrestrial sequestration activities, as there are several ways in which these risks may be addressed. Under the CDM, for example, forestry credits were assigned to a separate category of "temporary" or "term" credits. However, experience under this system has shown that temporary credits are not fungible with other credits and have received little market interest.

Although not widely debated, other forms of GHG emissions reductions can also be subject to future events that require alterations in carbon credits recognized during earlier time periods. Some, such as geologic sequestration, can suffer reversals when GHGs removed from the atmosphere are permanently released back into the atmosphere. Others, such as fuel switching, energy efficiency, or renewable energy projects that suffer equipment failures, can result in greater emissions in a particular year than would have occurred without the project, creating additional emissions that may require adjustments to credits recognized in earlier years.

Average carbon stocks on defined areas have been maintained in vegetation and soils over periods of time much greater than hundreds of years despite periodic carbon loss events.

Risks of Carbon Loss or Reversal

Projects may suffer carbon losses from a variety of causes over which the project owner may or may not have control (Table 2). While some carbon losses may constitute reversals, others may represent relatively minor change in carbon stocks over time. For example, fire can release CO2 into the atmosphere but it can also result in more rapid growth during the recovery period following the fire and delayed biomass degradation from charred dead wood pools. Certain projects have more inherent risk than others.

In addition, there is a difference between intentional and unintentional carbon loss or reversals. Intentional actions within the control of the project owner that result in reversals should be required to follow clearly defined requirements to replace affected credits quickly.

Policy can take into account the nature of reversals in that assessments can be made of the net result of the reversal over a distinct span of time and of the nature of the reversal act, whether intentional or unintentional. Project accounting can be designed with rules on how to account for all changes, regardless of intent of reversals that may be encountered.

Table 2. Risk of Carbon Loss and Owner Control over Risks

Risk of Carbon Loss	Owner Control	Carbon Loss
Natural	None-Low	Unintentional
Sociopolitical	None-Low	Unintentional
Technical	Low-Med	Unintentional
Financial	Low-High	Unintentional
Economic	High	Intentional

NATURAL HAZARD RISKS

While management measures can exacerbate or mitigate risks, natural hazards are largely beyond the control of the project owner. Natural risks of carbon loss include:

- **Wildfire** destruction of carbon stocks;
- **Disease** of crops or trees;
- **Insect** infestation of crops or trees;
- **Drought** leading to crop failure, crop-switching;
- **Wind** events, including hurricanes, tornados, micro-bursts; and
- **Floods and other natural disasters**, including tsunami, earthquake, landslide.

Sociopolitical Risks

Carbon assets can be lost due to changing regulatory policy, political instability, or social unrest, as well as due to leakage. In areas with inconsistent enforcement of property rights, sequestered carbon may be removed by trespass (e.g., illegal logging). In other cases unclear land tenure can lead to dispute and to a change of ownership and associated management practices. While destruction of carbon assets by outside actors may be less likely in some places, volatile farm policy and incentives can drive actions that affect carbon stores.

Technical Risks

In some cases carbon may be lost because the technologies or practices used (e.g., soil management, biochar, fertilizer management, crop rotation) fail to maintain carbon stocks as expected. Although technical losses may result, more likely technical risks would result in failure to achieve projected carbon benefits. Since carbon credits are not recognized until produced, these examples would not require any changes in accounting.

Financial Risks

Financial failure of an organization may lead to dissolution of agreements and change of management activities (e.g., increased harvest or land development).

Socioeconomic Risks

Higher-value alternative land uses and rising opportunity costs can lead to a change of management activity or plans. For example, rising land values can cause owners to convert agricultural land to development, high timber prices can lead to increased harvesting, and shifting crop prices or land rental values can lead to crop-shifting or to changes in tillage or other management practices. Price volatility in the carbon market can also influence management decisions away from the GHG-reducing or carbon-sequestering practices. Agricultural carbon projects are complicated by the fact that the entity managing the land is often not the landowner, and the need to maintain sequestered carbon often can outlive the land management agreement.

However, it is worth noting that related sociocultural issues also tend to reduce rapid or large-scale changes in management practices within the agricultural sector. Agricultural producers who maintain a certain practice from which they derive or observe benefits are largely resistant to changing practices unless they can see or be convinced of a greater benefit from the new practice. For example, most farmers who have converted to reduced tillage management of croplands find that the benefits of this change—which typically include improved soil tilth, fertility, and productivity as well as reduced inputs and erosion—make them resistant to change back from it. In addition, equipment used for no-till is different than that used for intensive tillage, so significant investments in equipment generally accompany such a change.

Tools for Managing Permanence Risk

Forestry and agricultural commodity markets have developed a wide range of tools to manage risk over long periods of time, and many of these tools can be used with future markets for offsets. Voluntary markets operating in the United States have also introduced new tools for risk management. This section briefly discusses some of the relevant tools. In general, markets will reward projects that have been designed or structured to reduce the risk of carbon loss or reversal.

Risks will change over time, and new tools will evolve to address them. For example, landownership in the United States has undergone dramatic shifts over the past few decades. In 2003 USDA stated that only 29% of the 927 million acres on U.S. farms and ranches were fully owned and operated by the landowner. In North Dakota, one of about a dozen states where extensive farm-level data are available, the management of cropland is far more likely to be by a tenant renter than by the actual landowner. According to the 2008 Annual Report of the North Dakota Farm Management Education Association, only 28% of land being farmed in North Dakota involves land owned by the land manager.

While it is common for outsiders to view farmers as landowners who have kept the family farm for generations, the reality of today's agriculture is largely absentee owners completely divorced from day-to-day (or even year-to-year) operations and management decisions. To achieve "permanent" sequestration or emissions reductions from changes in agricultural management, project eligibility rules and accounting procedures need to recognize the distinct roles of farm managers and landowners and to devise adequate risk management strategies for each group.

Standards
The most common risk mitigation strategy in commodity markets is standards. Standards define the things that will be measured to gain market entry and how they will be measured. Products that do not meet standards are not accepted for sale. Different grades are frequently assigned to differentiate product quality. Higher-grade products receive higher prices.

Discount, Implicit Reserve, or Risk Assurance Factor
Discussions for managing the risk of reversal in agricultural and forestry sequestration projects have been dominated by the issue of discounting. Most frequently, a discounted predefined risk coefficient is used to account for the probability of a carbon loss or reversal occurring over a set period of time for a defined region or project type—based on risk assessment. All project-based offset credits created are therefore discounted to account for risk of reversals. The disadvantage to this approach is that certain projects will outperform the assessment but with no additional associated credit, which in essence punishes innovative project managers.

Insurance Mechanisms
With all discount, buffer, or insurance mechanisms, the desire to maximize crediting must be weighed against the costs and accounting burdens of implementation. It is also true that there is no "one size fits all" option for managing permanence risk—any number of tools may be used, so long as the overall environmental outcome is assured. Several of these strategies will include assessing risks into the future, after a crediting period ends, to ensure against future reversals for a specified period of time (sometimes called a permanence or a liability period).

Project Buffer Account
Based on the risks of the specific project, a portion of offsets must be put into a buffer

reserve established for that project. Depending on the policy construct, these offsets may be recoverable by the owner if no reversals occur. This option is attractive in that projects may be registered and receive credits on an ongoing basis, with a final accounting at the end of the project crediting period. However, assessing risk and assigning a required buffer value on a project-by-project basis may be time-consuming and burdensome for individual (especially small) project owners and for the system administrators who must decide or approve the associated risk for each project.

Pooled Buffer Account
A program-wide pooled buffer account is maintained at all times by the program administrator. Project proponents will deposit buffer credits into the account. The amount of credits deposited depends on the estimated carbon loss for the projects in the aggregate, as estimated during a risk assessment process. Regular monitoring and recalibration of buffer withholding percentages can be used to adjust the size of the pooled buffer account based on actual loss experience. In other words, buffer withholding percentages can be adjusted across all projects based on actual loss experiences. This option removes the burdensome individual project accounting requirement, and the risk of overcrediting can be mitigated through conservative buffer approaches. This option is not attractive to many project developers who wish to receive the maximum number of offset credits available, as all projects are discounted at the same rate.

Insurance Contracts
Project proponents may purchase private insurance to cover the risk of carbon loss or reversals by a program. When a program has a buffer pool, the amount of the buffer would be adjusted to reflect the risk coverage provided by the insurance. As with project-based buffers, this option is attractive in that projects may be registered and receive credits on an ongoing basis. However, assessing risk and underwriting the insurance mechanisms on a project-by-project basis could be particularly costly and time-consuming for small project owners.

Pooled Vehicles
Project owners who have multiple projects may set aside a percentage of all credits to cover potential losses and create a form of pooled self-insurance. In these cases, programs requiring a buffer would recognize the reduced risk of project owners holding a pool of credits to insure their projects against loss. Appropriate measures (e.g., contracts) must be in place to ensure the availability of credits in the event of a reversal. For project owners with multiple small projects, this may offer an attractive hybrid option of pooled risk buffer and insurance. But once again, it may be overly burdensome for smaller projects.

Temporary Liability Mechanisms
Easements or project implementation agreements may legally require landowners to take actions that maintain carbon stocks or make compensation for some or all reversals over a predefined time period. Temporary liability approaches may be combined with insurance mechanisms to help landowners meet their obligations to compensate for carbon loss or reversals during the fixed time period (e.g., for carbon loss or reversals due to natural disturbances). The attractiveness of this option varies greatly with the length of the obligation and the nature of the project owner/project manager relationship. For landowners managing their own projects, a long-term easement may offer the best chance to maximize project crediting while ensuring that no intentional reversals occur. Unfortunately, this approach may also ensure the lowest level of non-landowner project manager engagement.

Term Offset Credits
A commitment period ("term") is defined for maintaining carbon stocks commensurate with the credits issued to a project. At the end of the term, the project landowner must either renew the commitment to maintain the carbon for another term or the credits issued to the project must be replaced (i.e., through the purchase and retirement of an equivalent number of allowances or other offset credits). Responsibility for replacing the credits is generally assigned to the final buyer of the credits. Liability for any reversals that occur prior to the end of a term is generally assigned to the landowner, who may participate in an insurance pool or buffer reserve

to help cover the liability. Under the Kyoto Protocol of the UNFCCC, there has been a demonstrated lack of market demand for these types of credits.

POLICY RECOMMENDATIONS

The environmental integrity of any carbon regulatory system, standard, or protocol requires mechanisms to address permanence and the risk of carbon loss or reversal. A number of approaches have been developed in voluntary and regulatory carbon markets to ensure compensation for carbon loss or reversal, during crediting periods, and for future reversals during a "permanence period." As such, the potential of carbon loss or reversal is not a sound reason to exclude potential carbon-reducing activities, as there are numerous ways in which these risks may be addressed.

The members of the Coalition on Agricultural Greenhouse Gases believe that programs and activities should provide for continued storage of sequestered carbon over timeframes that are meaningful in the context of mitigating climate change. One way to address the issue of permanence is "risk-based" analysis of the likelihood that a reversal of sequestered carbon could occur under the crediting period of the project and in the future for a designated period of time. Different project activities have different factors that increase or decrease the risk of reversals. Policy should also distinguish between intentional and unintentional reversals.

The voluntary carbon market is an important source of innovation and a test market for new or untried GHG offset or sequestration methodologies that could potentially be graduated to mandatory carbon markets as long as they meet the quality criteria standards established by the mandatory offset program.

Chapter 4. The Potential of Agricultural Projects and Practices to Reduce Greenhouse Gas Emissions and Increase Carbon Sequestration

Enormous potential exists for farms and ranches in North America to reduce GHG emissions and increase carbon sequestration—potential found everywhere from intensive dairy operations to extensively grazed ranches, from prime cropland to marginally productive wet fields and drought-prone areas. The activities that can reduce emissions on farms range from cutting-edge innovations using biochar pyrolysis and anaerobic methane digesters to simple practices like adjusting crop rotations or setting aside marginal areas for habitat restoration.

The wide scope of climate-beneficial land use activities means that almost every farmer can benefit directly or indirectly from properly crafted incentives for emissions reductions. In some cases, farmers may choose to participate directly in an offsets program, in which case they would go through the necessary steps of monitoring and verifying their reductions, receiving offset credits, and selling the credits like other farm commodities. In other cases, farmers may not be interested in selling offsets but they may implement emissions-reducing activities because they make sense for other reasons, such as enhancing soil productivity or operational efficiency.

To capture the benefits of these activities for GHG mitigation, it is important to ensure a net benefit to the atmosphere. Thus farmers must manage all GHGs associated with their production practices, particularly carbon dioxide, nitrous oxide, and methane. Management choices may decrease some GHG emissions while increasing others, so it is important to look at all the impacts and do a net accounting. For example, managing land to increase soil carbon stocks by increasing plant growth might also increase emissions of N2O—a far more potent greenhouse gas. The cumulative impacts of a set of practices must be evaluated in each situation, as the impact of a suite of management practices on net GHG emissions varies by climate, soil type, and other conditions.

C-AGG intends to catalog these opportunities by producing a series of brief overviews of emission reduction/carbon sequestration practices and project types. These overviews will highlight the potential scope for emissions reductions/carbon sequestration, estimate the benefits and other environmental values to farmers and to society, and identify some of the barriers farmers may face in the near term in implementing these practices and projects. These overviews will be posted on www.C-AGG.com as they become available and C-AGG invites experts and practitioners to comment on them. The initial set of treatments included in this chapter is not intended to be an exhaustive list, but it is meant to be a "living document," with new information and activities added over time.

Cultivation Systems

SOIL MANAGEMENT, COVER CROPS, AND CROP ROTATION

Farmers can safeguard existing soil carbon and promote new accumulation (sequestration) by protecting the reservoir of carbon already in their soils (e.g., by reducing tillage and erosion) and by promoting conditions for the growth of roots and soil microbes (e.g., by using nutrient-retaining cover crops and rotating crops to diversify the demands on soil). Such practices as soil management, cover crops, and crop rotation can both protect and build soil carbon and can reduce the need for inputs, thereby lowering costs and potentially generating revenues from carbon offsets.

- **Soil management** involves several agricultural practices that have been found to increase soil carbon stocks by increasing plant biomass or slowing the rate of soil organic matter decay.[xi] Reducing tillage, using cover crops, changing crop rotations, planting improved crop varieties, and managing fertilizer use are all practices that can contribute to increased soil carbon storage.[xii]

- **Cover crops**, or crops planted during fallow periods, increase biomass production per unit of land, reduce erosion, and can improve soil structure and reduce compaction. Increased biomass makes more organic carbon available to the soil by increasing plant residue, reducing erosion, and slowing plant matter decomposition. These effects also reduce the amount of carbon that is released back into the air as CO2 from the oxidation process, and more biomass is converted to soil organic carbon. Improved soil structure and reduced compaction also improve soil fertility and reduce N2O emissions. Cover crops like hay fix carbon in the soil through their extensive root systems. Leguminous cover crops also replenish nitrogen levels in the soil, acting as a natural fertilizer.
- **Crop rotation** is the practice of sequencing dissimilar types of crops in the same area. The practice protects soil fertility by avoiding the buildup of pathogens and weeds, replenishing nutrients, alleviating compaction, and, in the case of legumes, replenishing nitrogen. Rotating crops helps ensure that nutrients are used efficiently, reducing the need for additional inputs. By reducing the buildup of weeds and pathogens, crop rotation helps farmers use less pesticides, creating a double benefit for the atmosphere: the demand for fossil-fuel-intensive pesticides is reduced, and the vigor of carbon-rich soil microflora is improved.

The quantity of emission reductions from soil management, cover crops, and crop rotation will vary from farm to farm, soil to soil, and region to region. For example, U.S.-based studies show that altering the mix of crops or using cover crops can sequester an additional 0.37–1.1 t CO2e/ha/year.[xiii] Global studies show a slightly larger range of 0.3–1.16 t CO2e/ha/year.[xiv] Long-term (30-year) studies in Ohio have shown an increase of 1.08 t CO2e/ha/year from switching to a high-residue crop rotation (corn-oat-hay vs. corn-soybean).[xv]

It is difficult to cost-effectively quantify with a high degree of accuracy the amount of carbon in any particular field or the amount due to any particular management practice. Direct soil sampling can yield great accuracy, but it is prohibitively expensive. Furthermore, the effect of management is relatively small from year to year. As a result, scientists have difficulty quantifying the effect of changes in management without analyzing many samples of soil from fields. The costs of this analysis can easily outweigh the value of the additional carbon sequestered. Thus there is a scientific challenge to account for the spatial variability of soil carbon in more cost-effective ways than through direct soil sampling.[1]

No protocols currently exist for quantifying emissions or emissions reductions from the use of cover crops or crop rotations specifically. Several research efforts and protocol development processes are now under way in North America to address this challenge, including a draft quantification protocol for reduced summer fallow in Alberta, Canada, and two soil carbon sequestration quantification methodologies currently under peer review. In addition, process-based models are being tested for their ability to accurately quantify carbon sequestration for particular management processes.

TILLAGE MANAGEMENT

When soils are tilled, the decomposition of organic materials and soil organic carbon is accelerated, and a portion of the sequestered

1 "Soil carbon content can be accurately measured using modern dry-combustion carbon-nitrogen analyzers, and even older methods (e.g., wet-oxidation) provide acceptable accuracy and precision. Consequently, designing cost-effective sampling schemes is the main challenge in estimating carbon stock changes over larger areas." K. Paustian et al., Agriculture's Role in Greenhouse Gas Mitigation (Arlington, VA: Pew Center on Global Climate Change, 2006).

carbon is returned to the atmosphere. Conservation tillage, where the degree of soil disturbance is minimized, can reduce GHG emissions by slowing the decomposition of organic matter compared with conventional tillage. The amount of carbon stored through conservation tillage will depend on the crop type, the agro-climatic region, and the degree to which the tillage management system disturbs the soil.

A considerable number of U.S. farmers have adopted conservation tillage management because of other benefits, such as fuel savings from machinery, reduced labor costs, and increased soil quality. Conservation tillage may also create cost savings by lowering the amount of fertilizer that needs to be applied to achieve the same yield.

The emission reduction potential from conservation tillage per acre of cultivated land varies based on climate, soil, and crop type. According to the USDA's National Agricultural Statistics Service, approximately 320 million acres of land in the United States are current cultivated under principal crops (e.g., corn or soy). Since tillage management practices are most commonly and successfully applied to principal crops, there exists a large technical potential for emissions reductions from reduced tillage management. EPA analysis shows the total agriculture soil carbon sequestration potential to be 168 Tg CO2e per year (or 168 million metric tons of CO2e per year) net emissions below baseline, between the period 2010 to 2110 at a fixed carbon price of $15 per ton.[xvi] Farmers may achieve additional emission reductions from using less fuel and avoiding the emissions of applied soil nitrogen fertilizers.

In North America, two protocols have been developed for the quantification of emission reductions resulting from the implementation of tillage management practices. One, developed in Canada under a collaborative federal-provincial-territorial government process, has been adapted by the Province of Alberta's GHG Emissions Offset System. A second tillage management protocol was developed for the Chicago Climate Exchange, a voluntary and legally binding GHG reduction and trading system in North America.

FERTILIZER MANAGEMENT AND NITROGEN CONTROL

Agricultural use of nitrogen fertilizer plays a dominant role in generating agricultural emissions of nitrous oxide, a gas that is 310 times more potent for global warming than CO2. Excessive use of nitrogen in agricultural systems not only contributes to GHG emissions, it also impairs water quality, reduces biodiversity, and threatens human health.

Emission reduction opportunities in fertilizer usage fall into the following categories:

- Altered quantity of fertilizer applied,
- Altered placement of fertilizer application,
- Altered timing of fertilizer application,
- Altered type of fertilizer,
- Altered crop management practices (e.g., use of cover crops), and
- Management of runoff/leaching and associated indirect emissions.
- Adjusting fertilizer use is among the most cost-effective ways for farmers to reduce emissions of greenhouse gases into the atmosphere.

Because direct field measurement of N2O emissions is prohibitively expensive,[xvii] researchers continue to focus on building process models or simplified defaults based on direct measurement in experimental plots in various locations globally. Though the IPCC has issued guidelines for reporting N2O emissions under national GHG inventories, and EPA has adapted these guidelines for use in preparation of the U.S. inventory, the guidelines are based on highly simplified default data and therefore have not been accepted as a way to measure project-level benefits. Several other methodologies for more accurate model-based estimation of N2O emissions are under development, including the DNDC (de-nitrification and de-composition) model, the Alberta Nitrous Oxide Emission Reduction Protocol, the Winrock-Packard simplified methodology, and the DAYCENT model.

Recently, a protocol for emissions reductions credits from nitrogen fertilizer management for

N2O mitigation in corn production was proposed for use in the U.S. Midwest.[xviii]

BIOCHAR

Biochar, a fine-grained charcoal product made of carbon, can be used as a soil amendment, where it degrades very slowly and holds considerable promise for reducing GHG emissions while enhancing soils and increasing biomass and crop productivity. Biochar is produced by the thermal degradation of biomass (crop or forest biomass, animal manures, or other biomass wastes) in the absence of oxygen, via pyrolysis or gasification. This process effectively condenses carbon into a high-surface area charcoal product that decreases the decay rate of the carbon for millennia, greatly slowing the breakdown and release of carbon back into the atmosphere. Biochar has a mean residence time of 1,000 to 2,000 years in soils,[xix] thus creating "virtually permanent" soil carbon.

Biochar production technologies can be categorized into slow pyrolysis, fast pyrolysis, and gasification, and they may be stationary or mobile. The amount of bioenergy co-produced by biochar production systems will vary with the system and the production parameters, but the optimization of biochar production will reduce the energy co-product, and vice versa. Biochar systems may allow farmers to adjust their production to take advantage of changes in prices of carbon, energy, crop inputs, and biomass, though they may encounter trade-offs between flexibility and efficiency.

In addition to its capacity to reduce GHG emissions, biochar has many ancillary agronomic and environmental benefits. It is more stable than other soil amendments and has been shown to increase nutrient availability beyond a fertilizer effect, potentially making it more efficient at enhancing soil quality than other organic soil amendments.[xx] In preliminary studies, biochar has been shown to reduce nutrient leaching and N2O and methane emissions from soil, to enhance fertilizer-use efficiency, to improve soil nutrient retention and bio-availability of nutrients to plants, and to increase soil moisture retention, crop productivity, soil fertility, and soil structure.[xxi] Biochar production and utilization systems also offer significant waste management opportunities, both on-farm and off. However, biochar has not been thoroughly or systematically studied in all soils and climates, and differences in the pH or nutrient content of some products might make them more advantageous in some soils than in others.

Biochar systems are currently being used in industrial-scale and farm-scale applications, showing demonstrable benefits, including income generation, biochar for land application and/or sale, bioenergy co-production (bio-oils, syngas, thermal energy for on-farm utilization), and agronomic benefits. However, there is a need for continued development of biochar demonstration projects at all scales, including on the farm, to establish better data on all aspects of production and utilization, including data on the economics of various biochar systems.

Emission reductions associated with the carbon sequestration portion of biochar are relatively straightforward. Scientific evidence demonstrates that biochar is a very stable form of organic matter when added to soils, with an estimated mean residence time of 1,000 to 2,000 years.[xxii] However, biochar products have both a labile component and a stable component, and quantification (through testing) of the labile component is necessary to establish the proportion of carbon in the stable fraction of biochar for carbon trading schemes.[xxiii]

The technical global carbon reduction potential of biochar is conservatively estimated to be as high as 1 gigaton per year by 2054 (one "wedge").[xxiv] This estimate includes only the direct carbon reduction benefit of biochar, without accounting for renewable energy production and fossil fuel displacement, increased net primary productivity, or reduced soil N2O or CH4 emissions. Emissions reductions associated with the other climate mitigation aspects of biochar depend on the biochar system and environmental factors, but they can include avoided emissions from conventional use of feedstock biomass, avoided emissions of N2O and CH4 from soils amended with biochar, displaced fertilizer and agricultural inputs, and fossil fuel displacement (from syngas, bio-oils, and/or thermal energy created by biochar production technologies).

Carbon offset accounting methodologies for biochar are currently being considered by the Climate Action Reserve of the California Climate Action Registry and the Climate Trust of Oregon. In addition, a biochar offset accounting methodology has been submitted to the Voluntary Carbon Standard, where it is under review.

CROP RESIDUE AND WASTE MANAGEMENT

Crop residues from the field (e.g., leaves, seed pods, stalks, and stubble) and crop process waste (e.g., husks, seeds, bagasse,[2] and roots) can be managed in ways that reduce GHG emissions.

Management options for crop residue include leaving it on fields, plowing it back into soil, composting and then applying to soils, putting into landfills, or burning it in the field.[xxv] The material can also be used as fuel (feedstock), animal bedding material, supplemental animal feed, or construction material.[xxvi]

Depending on which management practice is used, varying amounts of GHG emissions may be released. Crop residue and other agricultural waste management practices can increase the nitrogen in the soil, thereby increasing the amount available for nitrification and denitrification, eventually resulting in the release of nitrous oxide. Based on its global warming potential, N2O is the dominant GHG released from crop residue.[xxvii]

Other management options include using crop residue as a biomass feedstock for liquid fuel or electricity production or for cellulosic ethanol. Though energy content varies among crop species, cereal crop residues have on average a heating value of 18.6 gigajoules per ton, which is 50% that of coal and 33% that of diesel, and a maximum biofuel energy of 5 exajoules per year.[xxviii]

However, the removal of crop residue can have a deleterious effect on soil quality. Returning crop residues to the soil improves its quality by controlling erosion, maintaining structure, moderating moisture and temperature regimes, providing energy for microbial processes, providing an important source of macro and micronutrients, and conserving organic matter content.[xxix] Conversely, removing crop residues can have negative effects on all these processes with important consequences for both soil health and agricultural productivity,[xxx] and it can transform soils from significant sinks of atmospheric CO2 to large sources.[xxxi] Studies have thus found that only 40% of corn residue can be collected without adverse effects on soil under continuous production[xxxii] and mulch-till[3] conditions, compared with 70% under no-till conditions.[xxxiii]

The United States accounts for 13% of the global 3.8 billion tons of residue produced each year, of which 300 million tons are from cereals,[xxxiv] which is the most usable form of residue. Some 33% of U.S. residues are produced in the Corn Belt and 25% in the Great Plains. For corn alone, over 90% of the 68 million tons of annual corn stover[4] is left in the fields[xxxv] and less than 1% is collected for reprocessing.[xxxvi]

As a whole, agricultural soils were responsible for 261.6 teragrams of CO2e in 2004,[xxxvii] with approximately 4% coming from crop residue.[xxxviii]

The amount of crop residue converted into soil organic carbon is largely dependent on a number of ecological factors, such as temperature, soil moisture content, and soil type, as well as

2 Bagasse is the fibrous residue remaining after sugarcane or sorghum stalks are crushed to extract their juices.

3 Full-width tillage involves one (or more) tillage trip that disturbs the entire soil surface and is done prior to and/or during planting. Tillage tools such as chisels, field cultivators, disks, sweeps, or blades are used. Weed control is accomplished with crop protection products and/or cultivation.

4 Stover consists of the leaves and stalks of corn (maize), sorghum, or soybean plants that are left in a field after harvest.

management practices that determine the amount and quality of residue left on the land, tillage techniques utilized, and the use of fertilizer, irrigation, and crop type.[xxxix] Some studies have shown that the lignin content of residue is strongly positively associated with soil organic carbon content.[xl]

It has been estimated that the U.S. technical potential of carbon sequestration through residue management on croplands is 22.5 million metric tons of carbon per year.[xli]

The IPCC 2006 guidelines include recommendations on measuring emissions reductions associated with crop residue management. (See http://www.epa.gov/climatechange/emissions/downloads09/Agriculture.pdf.)

IRRIGATED RICE CULTIVATION

Virtually all domestic rice is grown in flooded conditions. This presents unique circumstances for GHG emissions compared with most other agricultural commodities. Anaerobic decomposition, which occurs in flooded fields, generates significant amounts of methane, while aerobic decomposition associated with non-flooded agriculture produces CO2. In 2005, rice emissions were 56 million metric tons of CO2e in the United States (1% of total U.S. agricultural emissions).[xlii]

The literature on emission reduction opportunities associated with flooded rice derives primarily from studies in Asia, which has significantly different cultivation practices than the United States.[xliii] Within the United States, attention on GHG emissions reductions in rice has centered on California. Rice cultivation in the U.S. South entails different practices and growing conditions, and further research is needed before concluding that the experience in Asia or California will translate to that area.

Emissions reduction opportunities in rice include:

- **Altered paddy flooding (timing and duration).** Activities that shift decomposition from anaerobic to aerobic conditions can shift emissions from methane to carbon dioxide. DNDC modeling and experimental results indicate that on certain soil types in California, emission reductions of nearly 1 ton CO2e/acre/year are possible, largely from reductions in methane emissions.[xliv]
- **Residue management**. Practices for removal of postharvest rice straw residue vary by region in the United States but fall into three general categories: burning, anaerobic decomposition (i.e., incorporation of residue and re-flooding fields), and rice straw harvesting. Burning rice straw has air quality side effects and is in decline in some rice production areas, namely California. Anaerobic decomposition of rice straw results in significant CH4 production and a net increase in GHG pollution. Rice straw harvesting can result in a net emissions reduction when it displaces anaerobic decomposition and when the ultimate decomposition of the rice straw produces CO2 rather than CH4.
- **New varieties**. Use of higher-yielding varieties can reduce CH4 emissions compared with lower-yielding varieties.[xlv] Higher-yielding varieties direct more carbon into grain production and therefore leak less into the atmosphere via anaerobic decomposition. Specific quantification of this potential is not yet available.

Direct field measurements of CH4 and N2O emission reductions can be quite expensive, and therefore researchers have focused on building process models based on direct measurement in experimental plots in various locations globally. Quantification methodologies for emissions reductions from rice cultivation are currently based primarily on the DNDC model being developed by the Environmental Defense Fund and the California Rice Commission through a joint project funded by USDA.

Livestock Systems

DAIRY AND INTENSIVE LIVESTOCK OPERATIONS

GHG emissions from the raising of livestock can include emissions associated with enteric fermentation processes in addition to the decomposition of manure, among other sources. Farmers may be able to reduce GHG emissions by focusing on lowering the emissions intensity or improving the efficiencies of retained energy in the feed of livestock.

Emissions intensity is a measure of the amount of greenhouse gases produced by an animal for each unit of production (e.g., gallon of milk, pound of live weight). For ruminants, such as cattle, the emissions with the greatest impact are methane produced through enteric fermentation. These emissions are the by-product of digestion that are exhaled or eructated (belched) by ruminant animals like dairy and beef cattle. One strategy to reduce emissions from cattle is to use feed additives, such as edible oils, ionophores, or distiller's grains, which can inhibit the formation of methane by rumen bacteria. Other methods, such as adjustments to the lifecycle (e.g., moving cattle through the system to slaughter at earlier ages) or reducing the days in the feedlot by increased efficiencies, may also reduce related emissions. Another strategy, where cattle are selected for their net feed intake (i.e., breeding those cattle that gain more weight with similar amounts of feed as their neighbors) is under development in Alberta.[xlvi]

Alternatively, for non-ruminant animals such as swine, manipulations in feed rations or improvements in feeding technologies increase the feed conversion efficiency (FCE) rates for these animals. (FCE is a measure of an animal's efficiency in converting feed mass into increased body mass.) FCE gains decrease the amount of manure that is excreted by a pig, resulting in fewer manure-related emissions from decomposition (i.e., during the spreading of manure on fields).

In addition, other methods that increase feed efficiency or manage emissions related to the production of dairy cattle feed can be implemented. Potential opportunities for efficiency gains can be achieved in the following areas:

- Milk productivity: better genetics or husbandry to achieve equal milk with less feed,
- Diet modification: higher-quality feed or supplements (edible oils or ionophores) to decrease enteric methane per unit feed,
- Replacement rate: fewer non-productive cows, and
- Pasture: avoid emissions associated with processing feed.

A Dairy Management Protocol has been approved in the Alberta Offset System.

In 2007, enteric fermentation and manure management were responsible for 131 million tons and 59 million tons of CO2e emissions, respectively, in the United States.[xlvii] With U.S. cattle and hog inventories of approximately 94 million and 9.6 million heads, respectively, small reductions in emissions associated with each animal could lead to noteworthy reductions overall.

Four protocols have been adapted and developed under the Alberta Offset System in 2007–08, addressing the GHG emission reductions that could be achieved from the following activities:[xlviii]

- Reducing the slaughter age of cattle,
- Reducing the days cattle are on feed,
- Feeding edible oils to cattle, and
- Innovative feeding of swine.

MANURE MANAGEMENT

The decomposition of manure can result in the release of methane, nitrous oxide, ammonia, and carbon dioxide into the atmosphere. A number of factors are responsible for GHG emissions from livestock manure, including the quantity of manure produced, the manure's characteristics, how the manure is managed and stored, and geographic location.[xlix]

Over the past few decades, manure management systems have seen a marked increase in emissions due to a variety of factors, including a shift from small farms that generally use dry manure management systems to larger farmers that tend to use liquid systems (usually in the form of open lagoons). In traditional management systems, the manure was deposited in pastures or corrals and subsequently collected and applied as a fertilizer to croplands, thus allowing it to decompose aerobically or to remain in constant contact with air, which releases very small amounts of methane.[l] However, larger dairy and swine farms—which have become more common over the past two decades—often use liquid manure management systems that use water to flush the alleyways or pits where the manure is deposited.[li] In these liquid or "slurry" systems, the manure is then collected and stored in concrete tanks or lagoons until it can be applied to cropland through irrigation methods. This process creates optimal conditions for methane production, since the manure is stored is a water-based environment with high level of nutrients for bacterial growth.[lii] Methane production is especially prominent in dairy and pig farms, whereas beef, poultry, and other livestock farms do not generally use liquid manure systems.

Anaerobic manure digesters offer significant GHG emissions abatement potential. Manure digesters are specially designed insulated tanks that are used to facilitate the anaerobic digestion process under a controlled atmosphere. These tanks decompose the manure in a controlled environment, recover the methane produced (known as biogas), and either combust it or capture it and use it as an energy source. A variety of anaerobic digestion technologies are available.

Rising fuel costs and growing concerns about the environment have increased recent interest in biogas as a potential renewable fuel source to displace fossil fuels in heat and electricity production. As such, the anaerobic treatment of agricultural wastes, including manure and crop residues, presents an opportunity to reduce methane emissions associated with the decomposition of organic matter, in addition to reducing emissions from the combustion of fossil fuels in the generation of heat and electrical energy. The digestate, or solid material, produced as a by-product of anaerobic digestion can also be applied as a fertilizer, displacing fossil-fuel-based chemical fertilizers.

In the United States, livestock produce over 1 billion tons of manure on an annual basis.liii According to a study conducted by the University of Texas, much of this manure is either stored in lagoons or left outdoors to decompose.[liv] The decomposition of animal waste is a large source of U.S. GHG emissions, accounting for approximately 14% of GHG emissions from the agriculture sector between 2005 and 2007.[lv]

As of February 2009, EPA estimated that only 125 farm-scale anaerobic digesters were operating at commercial livestock farms in the United States.[lvi]

Riparian Areas and Wetland Restoration

Wetlands naturally sequester atmospheric carbon and perform other valuable ecological functions. The latest inventory of GHG emissions and sinks for the United States listed prairie wetlands in Conservation and Wetland Reserve Program lands as carbon sinks.[lvii] Restoring wetlands can sequester atmospheric CO2 and mitigate GHGs generated by agriculture, in addition to having other important ancillary benefits, such as enhancing organic stocks of soils to ensure the sustainability of food production, providing habitats critical to the maintenance of biodiversity, retaining surface water to mitigate flooding, and improving water quality in streams and rivers.

With an average net primary productivity of 1,180 grams of carbon per square meter per yearlviii and a surface area of 7–9 million hectares,[lix] wetland ecosystems store more carbon per hectare than any other ecosystem.[lx] The size of the historic wetland carbon sink in the prairie pothole region of North America was recently estimated at 378 million tons CO2e,[lxi] with over half (197 million tons) of the total carbon stores lost to the atmosphere from cultivation of farmed or drained wetlands. An Agriculture–Wetlands GHG Research Initiative, involving multiple benchmark sites in the prairie pothole region of Canada, recently showed that newly restored wetlands were found to sequester 0.86 tons of CO2e per hectare per year.[lxii] In other areas of the United States, the wetland losses and carbon sinks were significantly larger than in the pothole region of the Great Plains.

Agricultural management practices can also affect the carbon sequestration taking place in remaining wetlands. In sediments from eroded soil that migrates to wetlands, organic carbon decomposes and liberates methane, while nitrous oxides from agricultural fertilizers are emitted along wetland margins. Existing carbon sinks in wetlands have and continue to be lost through four primary mechanisms:

- Drainage of wetlands,
- Farming of wetlands,
- Decomposition of historic soil organic materials,
- Application of fertilizers, which increases the emission rates of trace GHGs.

The following management strategies can help farmers reverse the continued deterioration of wetlands and emissions of GHGs from them and can reverse these trends to begin sequestering and rebuilding soils in wetlands:

- **Cease Artificial Drainage of Wetlands and Hydric Soils**. Draining historic wetland soils and exposing deeper soils to the decomposition process can be avoided by farming historic wetlands soils only when they seasonally dry down and by confining the agricultural uses to only those areas that dry down adequately to support agricultural uses. Farming these wetlands will release the stored carbon they accumulated in prior wet periods when they were not farmed. Also, unless protected with grassy buffers, farmed wetlands have the potential to emit large quantities of N2O from their margins and methane from the anoxic portions of the flooded basin.[lxiii] For GHG management, these systems may fare best if not farmed.
- **Reduce Mechanical Disturbance of Soils**. Existing carbon stocks found in the soil can be protected from decomposition and the release of carbon into the atmosphere by reducing the mechanical disturbance of seasonally drained wetland soils by annual tillage (disking, plowing, rototilling, etc.). The use of no-till seeding techniques may, for example, allow for the continued use of seasonally dry wetland soils while minimizing carbon loss.
- **Restore Hydrology of Wetlands**. Restoring degraded wetlands, particularly wetland hydrology, may be the most effective way to influence carbon sequestration in wetlands. In fact, ongoing studies show a general reduction in GHG emissions from most wetland restorations and suggest wetland restoration to be a most important strategy for enhancing carbon sequestration in wetlands.[lxiv] Once hydrology is restored, the water-saturated and waterlogged environment reduces the decomposition potentials and rates annually as plant matter dies back. A very rapid accumulation of plant matter (sequestered carbon) can build up, and in the least affected currently drained wetlands significant levels of lost carbon may be replaceable by hydrological restoration over a decade or so.
- **Buffer Wetlands from Fertilizer and Nutrients**. Wetland buffers can be used to mitigate sediment and nutrient import into wetlands and to curtail the subsequent wetland enrichment process and the release of trace gas emissions (CH4 and N2O). The buffer idea can be extended into the upland drainage areas to retain topsoil, reduce runoff to wetlands in high-gradient areas, and hence reduce sediment and nutrient import into wetlands.
- **Restore the Biodiversity of Wetlands**. Relationships between biotic and hydrogeochemical attributes in healthy wetlands contribute to reduced emissions of trace GHGs. The soil bacteria and fungi, and some plants, have the capacity to use nutrients very effectively, making them less vulnerable to releasing trace gas emissions. Disturbances can reduce their efficiency at removing available nitrogen declines, causing an increase in nitrous oxides, methane, and other trace gases.

Programs such as the Wetland Reserve Program of the Natural Resources Conservation Service, U.S. Fish and Wildlife Services programs for wetland protection and restoration, and numerous ones administered by private organizations (e.g., Ducks Unlimited, The Nature Conservancy, Prairie Enthusiasts, LandKeepers, and farm organizations) can facilitate wetland restoration and management efforts by farmers.

However, the costs of monitoring and verification are likely to be high for GHG reductions from wetlands, because trace gas emissions are ephemeral and costly to measure.

Chapter 5. Policy Recommendations

Well-designed climate policies can support rural economic development and advance agricultural goals. The Coalition on Agricultural Greenhouse Gases has developed five policy recommendations for incorporating agricultural GHG emissions reduction activities into U.S. climate change policies and programs.

In summary, C-AGG believes that U.S. climate policy should:

- **Use a variety of policies and programs** to encourage GHG abatement in the U.S. agricultural sector.
- **Use the best available science and technology** to develop and reward GHG abatement activities in the U.S. agricultural sector.
- **Enable the federal government to create institutional arrangements that promote and facilitate improved GHG data collection and analysis**, and ensure accessibility of accurate, current data for all stakeholders.
- **Promote and encourage additional/ancillary benefits and positive impacts wherever possible**, and prevent or minimize any adverse impacts.
- **Enable the voluntary market to play a role in the transition to a fully regulated U.S. greenhouse gas market**, particularly through the development of early offset credits and methodologies.

This chapter provides some details of these recommendations.

First, use a variety of policies and programs to encourage GHG abatement in the U.S. agricultural sector. Agriculture depends on many diverse biological processes and includes a great number of equally diverse actors in managed landscapes. Encouraging changes in practices that achieve quantifiable net GHG reductions in the agricultural sector will require a coordinated framework of programs and policies. Recognizing this complexity, C-AGG recommends the following approaches to maximize voluntary GHG reductions and increased carbon sequestration from agriculture.

1. GHG offsets and allowance set-aside payments should be made to agriculture within climate policy.

   Offset credit should be issued for real, additional, measurable, verifiable, and permanent or maintained reductions in GHG emissions and increased sequestration.

   Allowance allocation "set asides" can be used to:

   - reward farmers for actions that may not be suitable for inclusion in an offset program,
   - recognize early actors/early actions,
   - fund vital research and development for new GHG emission reduction or increased sequestration activities or technologies, and
   - improve GHG measurement and monitoring tools and techniques.

2. Greenhouse gas mitigation activities that produce measurable, verifiable reductions in GHGs should be incorporated into existing and new Farm Bill programs. Methodologies for agricultural offset credits should be completed by the appropriate federal agency, taking into consideration existing methodologies, within 24 months of enactment of federal climate policy in order to provide market certainty to investors and the agricultural sector.

3. Early action credits, if they are considered, should be awarded in a way that protects the

integrity of the overall mandated reduction (or "cap") on the regulated sectors. Awarding set-aside allowances for early action credits is one way to accomplish this.

Second, use the best available science and technology to develop and reward GHG abatement activities in the U.S. agricultural sector.

1. GHG abatement programs for the agricultural sector should strive toward measured GHG reduction outcomes, when possible, and away from practice-based crediting.

    a. Wherever possible, crediting should be based on scientifically and statistically sound measurement methods rather than being awarded solely on the implementation of a specific practice.

    b. The GHG offset program administrator should evaluate where performance-based crediting systems are possible, and where practice-based crediting methods might be appropriate proxies for performance.

    c. Practice-based crediting methodologies are appropriate if the level of uncertainty in performance as a result of a particular practice can be adequately characterized and accounted for.

2. Accurate, reliable, and affordable measurement and quantification tools and technologies for GHG emissions reductions and increased sequestration within the agricultural sector are needed. A major investment in research and technology development associated with measuring agricultural GHG emissions and carbon sequestration is needed in order to realize agriculture's full GHG mitigation potential. In order to overcome these barriers, research is needed to:

    a. Reduce the costs and improve the accuracy of GHG measurement technology;

    b. Further develop and calibrate modeling tools for a wide range of applications, such as for additional crops, geographies, and management practices;

    c. Enhance access, coordination, and reliability of data sets used for GHG measurement, monitoring, and modeling, particularly across federal agencies; and

    d. Develop comprehensive GHG accounting frameworks for farm-scale agricultural activities. These should quantify and account for all relevant GHG sources and sinks; consider additionality; account for any leakage of emissions outside a project's boundaries that may occur as a result of the implementation of a project, when possible; address permanence and risk of reversal; and distinguish between intentional and unintentional reversals.

3. GHG policies, programs, and rules must incorporate mechanisms that allow for adaptation and adjustment over time to accommodate emerging science, knowledge, technologies, and best practices.

    a. GHG policies should require regularly scheduled reviews of crediting methodologies, processes, and mechanisms.

    b. Programs should allow for needed program adjustments to incorporate the latest science, best practices, and best methodologies.

4. Balancing the economic costs of policies and programs and the GHG and economic benefits is an important issue for the agricultural sector and should be carefully considered in the design of federal GHG programs.

5. A better understanding of the relative costs, and the cost benefits, of emission reduction

opportunities in the agricultural sector is needed.

Third, enable the federal government to create institutional arrangements that promote and facilitate improved GHG data collection and analysis, and ensure accessibility of accurate, current data for all stakeholders.

1. The appropriate federal agency should develop a standardized framework for data collection and analysis for the agricultural sector, which should include participation by other federal agencies with relevant land use jurisdictions and data.

2. The appropriate federal agencies should develop a comprehensive method to catalog and rank various agricultural systems, practices, and activities by region in order to provide estimates of the potential for each to provide net GHG emissions reduction or increased sequestration, and they should evaluate their costs.

3. The system should allow comparative assessments, including cost-benefit analyses across systems and activities to help focus public and private investments on methodologies and protocols for potential market-based offset credits.

    a. The system should help discern which activities qualify for carbon offset credits and which are best addressed through other policies (e.g., through allowance set-asides or farm bill program adjustments).

    b. The system should provide a national pooling of available publicly funded data on soil carbon time series data that document changes in soil stratography, levels of total carbon, soil organic carbon, and soil inorganic carbon, and well-organized geographic databases should be created for stakeholders to use in developing performance-measurement-based carbon projects.

    c. Comprehensive information access, transparency, and accountability provisions should be established for all rulemaking, monitoring, and verification processes associated with the offset program.

Fourth, promote and encourage additional/ancillary benefits and positive impacts wherever possible, and prevent or minimize any adverse impacts. Climate change mitigation policy should take into consideration other ecosystem services, adaptation, and sustainability considerations in order to promote multiple environmental benefits and to prevent or reduce negative environmental impacts.

1. Existing and developing environmental markets beyond GHG markets should be evaluated, and market opportunities for all agricultural stakeholders and participants should be developed where appropriate. An office established to promote ecosystem services within USDA, called the Office of Environmental Services, has begun work on evaluating existing ecosystem services and markets.

2. Accounting frameworks should be developed to accurately assess and evaluate the interactions between various environmental impacts/ outcomes that occur as result of practices implemented due to environmental markets.

3. If multiple environmental commodities are "stacked" (e.g., generating GHG offset credits as well as water quality credits from practices implemented by an agricultural producer), credits should only be awarded for incremental environmental outcomes in order to ensure additionality and prevent double-counting. Further research and policy development is needed to determine best practices and the optimal means of crediting multiple environmental commodities from a single project, activity, or geographic area.

4. Early warning systems and monitoring procedures should be developed to identify any potential unintended negative environmental or other impacts that might occur as a result of the implementation of GHG mitigation activities as soon as possible, including within the land use, agricultural, and forestry sectors. This will enable those impacts to be addressed as quickly as possible.

5. Regulations governing the eligibility of different project types should include appropriate safeguards to protect against negative impacts on public health and/or the environment, including the destruction or temporary conversion of native habitats.

6. Agricultural GHG mitigation efforts should result in net emissions reductions or increased sequestration.

    a. Methodologies to assess aggregate GHG impacts at regional, national, and ultimately, global scales should be developed.

    b. Methodologies should be developed to ensure GHG accounting occurs at the national and international levels wherever possible, and not just at the project level. This will ensure that all relevant GHG emissions are properly accounted for.

Fifth, enable the voluntary market to play a role in the transition to a fully regulated U.S. greenhouse gas market, particularly through the development of early offset credits and methodologies. The voluntary carbon market is an important source of innovation and a test market for new or untried GHG methodologies that could potentially be graduated to mandatory markets as long as they meet the quality criteria standards established by the mandatory offset program.

1. Voluntary markets allow investors and agricultural producers to gain experience and to perfect methodologies and protocols for transactions; they are an important component of long-term GHG mitigation strategies.

2. Existing agricultural methodologies should be prioritized for review and potential approval by the offset program administrator as soon as possible after passage of climate legislation.

3. The offset program administrator should give priority to the development of high-quality agricultural offset methodologies within the first 24 months of the program.

4. A rationale and process for assessing credit for early action projects should be established to provide certainty to participants and investors. Credit should be targeted at activities that reward early actors and early actions to protect and prevent the reversal of existing carbon stocks created or enhanced by these actors/actions, and to avoid perversely penalizing actors/actions taken in advance of mandatory carbon markets.

Glossary

Accuracy The agreement between a measurement and the true or correct value. If a clock strikes 12 when the sun is exactly overhead, the clock is said to be accurate. The measurement of the clock (12) and the phenomenon it is meant to measure (the sun located at zenith) are in agreement. Accuracy cannot be discussed meaningfully unless the true value is known or is knowable.

Additionality The concept that greenhouse gas emissions reductions for credits must result from additional action or action that likely would not have happened in the absence of the incentive provided by the carbon market.

Alberta Offset System A regulatory compliance system for managing greenhouse gases that uses a market-based approach to allow regulated firms in the Canadian province of Alberta to buy verified emission reductions and/or removals of greenhouse gases (i.e., offsets) from voluntary actions arising from unregulated activities (i.e., offset projects in Alberta).

Baseline Typically establishes some standard against which the GHG benefits of a project can be evaluated. A baseline can take different forms, such as a project-by-project approach or a benchmark or performance standard for a sector or region. Furthermore, baselines may be static or dynamic (i.e., change over time). For agricultural and forestry projects, the baseline could be the level of GHG emissions or carbon sequestration that would occur in the absence of project implementation.

Biochar A form of charcoal created by thermal degradation of biomass under controlled conditions that limit or exempt the presence of oxygen. Biochar differs from other forms of charcoal in the sense that its primary use is not for fuel but for biosequestration or atmospheric carbon capture and storage. Biochar is of increasing interest because of its potential to remove atmospheric carbon for millennia.

Carbon dioxide equivalents Weight of carbon dioxide released into atmosphere having the same estimated global warming potential as a given weight of another gas. It is computed by multiplying the weight of gas (methane, for example) by its global warming potential (21 for methane).

CENTURY model A general model of plant-soil nutrient cycling that is being used to simulate carbon and nutrient dynamics for different types of ecosystems, including grasslands, agricultural lands, forests, and savannas. The CENTURY model is composed of a soil organic matter/ decomposition submodel, a water budget model, a grassland/crop submodel, a forest production submodel, and management and events scheduling functions. It computes the flow of carbon, nitrogen, phosphorus, and sulfur through the model's compartments. The minimum configuration of elements is carbon and nitrogen for all the model compartments. The organic matter structures for carbon, nitrogen, phosphorus, and sulfur are identical; the inorganic components are computed for the specific inorganic compound.

Chicago Climate Exchange (CCX) North American's only voluntary, legally binding greenhouse gas reduction and trading system for emission sources and offset projects in North America and Brazil.

Clean Development Mechanism (CDM) An arrangement under the Kyoto Protocol of the U.N. Framework Convention on Climate Change allowing industrialized countries with a greenhouse gas reduction commitment to invest in ventures that reduce emissions in developing countries as an alternative to more-expensive emission reductions in their own countries. The CDM allows net global greenhouse gas emissions to be reduced at a much lower global cost by financing emissions reduction projects in developing countries, where costs are lower.

Climate Action Reserve The new name for the California Climate Action Registry (CCAR). CCAR has traditionally been a registry for GHG emission inventories, but through its transformation to the Reserve it is now focused on developing standardized GHG reduction project protocols and a system that registers and tracks GHG offsets through a publicly accessible database.

COMET-VR (Voluntary Reporting of Greenhouse Gases-Carbon Management Evaluation Tool) A decision support tool for agricultural producers, land managers, soil scientists, and other agricultural interests. COMET-VR provides an interface to a database containing land use data from the Carbon Sequestration Rural Appraisal and calculates in real time the annual carbon flux using a dynamic CENTURY model simulation. Users of COMET-VR specify a history of agricultural management practices on one or more parcels of land. The results are presented as 10-year averages of soil carbon sequestration or emissions with associated statistical uncertainty values.

CStore A new model being developed by Colorado State University to quantify and assess soil carbon stock changes in agricultural systems as a function of different management practices. Unlike most existing soil carbon models, which have been used primarily for research support and large-scale assessment activities, the model is intended for use by non-specialists for field-level prediction and decision support, with a minimum of data requirements. Thus it is suitable for estimating soil carbon changes for different management practices and can be used in project design, forecasting, and quantification. The model is based on the CENTURY model, in a much simplified form. It includes two crop residue pools and three soil organic matter pools for which the main factors influencing decomposition and soil organic matter stabilization are monthly climate variables (temperature and precipitation), soil drainage status, soil texture, and management. The input information required by the model includes monthly minimum and maximum temperature and precipitation; surface soil texture; hydric or non-hydric soil; if hydric, approximate time since soil drainage, if any; approximate time since conversion to cropland from pasture/woodland, if occurring since 1920; biomass amount and type applied to the field or remaining after harvest; dates of residue/amendment additions and type and timing of tillage operations. The model can compute an estimated initial organic matter content, or, if known, initial organic matter contents can be input by the user. Climate and soils data can be specified from state and county pop-up menus or can be input directly for a specific location. Recent and projected crop rotations, tillage operations, and yield levels can be input directly or specified from state and county default menus.

DAYCENT model The daily time step version of the CENTURY biogeochemical ecosystem model developed for soil carbon dynamics, developed by Colorado State University and the Agricultural Research Service of the U.S. Department of Agriculture. DAYCENT simulates exchanges of carbon, nutrients, and trace gases among the atmosphere, soil, and plants as well as events and management practices such as fire, grazing, cultivation, and organic matter or fertilizer additions. Primary model inputs are soil texture, current and historical land use, and daily maximum/minimum temperature and precipitation. DAYCENT includes submodels for plant productivity, decomposition of dead plant material and soil organic matter, soil water and temperature dynamics, and nitrogen gas fluxes. Flows of carbon and nutrients are controlled by the amount of carbon in the various pools, the nitrogen concentrations of the pools, abiotic temperature/soil water factors, and soil physical properties related to texture. The ability of DAYCENT to simulate crop yields, soil carbon levels, and greenhouse gas fluxes has been tested using measurements from native and managed systems in the United States and around the world. Since 2005 DAYCENT has been used to estimate N2O emissions from cropped and grazed soils for the U.S. National GHG Inventory. The model is also used to investigate how land use and climate change affect plant growth and soil carbon and nitrogen fluxes. DAYCENT has many of the same inputs and outputs as DNDC; a major difference is that DNDC simulate soil redox potential and CH4 emissions from saturated soils whereas DAYCENT does not simulate CH4 production. Both models simulate CH4 uptake by non-saturated soils.

DNDC model A model dealing with denitrification and decomposition, two processes dominating losses of, respectively, nitrogen and carbon from soil into the atmosphere. The DNDC model was built up by integrating a group of biochemical and geochemical reactions commonly occurring in agroecosystems, which govern carbon and nitrogen transport and transformation in the plant-soil systems. DNDC simulates the processes of decomposition, nitrification, denitrification, and fermentation, which dominate NH3, CO2, N2O, and CH4 emissions and nitrate leaching losses from the soils. A relatively complete set of farming management practices such as tillage, fertilization, manure amendment, irrigation, flooding, grazing, etc. have been parameterized in DNDC to regulate their impacts on soil environmental factors (e.g., temperature, moisture, pH, redox potential, and substrate concentration gradients). By precisely simulating the soil microbial activities, DNDC links carbon sequestration to N2O or CH4 emissions. During the past decade, DNDC has been independently tested by a number of researchers worldwide with promising results. It can be applied at various scales, ranging from site-specific applications to quantify within-field variability to county and regional scales to account for differences in environmental conditions and management practices. The model is currently applied for greenhouse gas inventory or mitigation in North American, Europe, Asia and Oceania.

Empirical models A form of model used to estimate greenhouse gas emissions reductions by using field measurements to develop statistical relationships between soil carbon levels and agricultural management factors.

Error The disagreement between a measurement and the true or accepted value.

EU ETS (European Union Emissions Trading Scheme) Commenced operation in 2005 as the largest multicountry, multisectoral Greenhouse Gas Emission Trading System worldwide.

Feed conversion efficiency A measure of an animal's efficiency in converting feed mass into increased body mass.

GHG models Like all models, establishes correlations to develop a more comprehensive understanding and accounting of system changes and dynamics. GHG models can scale up point measurements of agricultural GHGs to the farm scale or even to entire landscapes.

Global Warming Potential (GWP) A different estimated impact of each greenhouse gas on global warming. An index accounts for the potential of each gas to heat the atmosphere, known as the radiative forcing impact over a specified time period (usually 100 years). The GWP translates the impact of one ton of a GHG emitted now relative to the impact of one ton of CO2 over the same period. By definition, the GWP of CO2 is one, with the GWP values for all other GHGs being greater than one. For instance, the GWP of methane ranges from 21 to 25 and the GWP of nitrous oxide ranges from 298 to 310, depending on the authoritative source.

Intergovernmental Panel on Climate Change (IPCC) The leading body for the assessment of climate change, established by the United Nations Environment Program and the World Meteorological Organization to provide the world with a clear scientific view on the current state of climate change and its potential environmental and socioeconomic consequences. The IPCC is a scientific body. It reviews and assesses the most recent scientific, technical, and socioeconomic information produced worldwide relevant to the understanding of climate change. It does not conduct any research, nor does it monitor climate-related data or parameters. Thousands of scientists from all over the world contribute to the work of the IPCC on a voluntary basis. Review is an essential part of the IPCC process, to ensure an objective and complete assessment of current information. Differing viewpoints existing within the scientific community are reflected in IPCC reports.

Leakage Typically defined as an increase or decrease in emissions that occurs outside an offset project's accounting boundaries as a result of the project and that is not otherwise accounted for by the project.

Measuring Soil C Stock Changes An essential component of agricultural carbon sequestration projects. Approaches for quantification can include direct measurement, model-based approaches, or a combination of these. Advantages to model-based approaches as a component of an overall uantification/verification framework include the low cost compared with direct, sample-based measurements and the ability to make projections into the future of anticipated outcomes (i.e., tons per hectare of sequestered carbon) of different management practices. This latter function can help in initial project development and in preliminary valuation and structuring of contracts.

NASA-CASA model (Carnegie-Ames-Stanford Approach) Simulates net primary production (NPP) and soil heterotrophic respiration (Rh) at regional to global scales. Calculation of monthly terrestrial NPP is based on the concept of light-use efficiency, modified by temperature and moisture stress scalars. Soil carbon cycling and Rh flux components of the model are based on a compartmental pool structure, with first-order equations to simulate loss of CO2 from decomposing plant residue and surface soil organic matter pools. Model outputs include the response of net CO2 exchange and other major trace gases in terrestrial ecosystems to interannual climate variability (1983 to 1988) in a transient simulation mode.

NUGGET-DNDC (Nutrient and Greenhouse Gas Evaluation Tool) an early version GIS Web prototype designed for estimating and analyzing nutrient releases to air and water from agricultural managements. End users of the prototype include crop consultants, farm managers, natural resource managers, and policy makers. At the center of NUGGET lies the DNDC soil biogeochemical model, which is designed to assess the impact of management strategies on the fate of nitrogen and carbon in groecosystems. DNDC integrates crop growth processes with soil biogeochemistry. The main goal behind the NUGGET concept is to enhance the information used by planners and decision makers working to evaluate agricultural management strategies and their associated environmental impacts.

Nutrient Trading Tool (NTT) Compares agricultural management systems to calculate a change in nitrogen, phosphorous, sediment loss potential, and crop yield. Agricultural producers and land managers can enter a baseline management system and an alternative conservation management system and produce a report showing the nitrogen, phosphorous, sediment loss potential, and crop yield difference between the two systems. The NTT was designed and developed by the Natural Resources Conservation Service and the Agricultural Research Service of the U.S. Department of Agriculture and by the Texas Institute for Applied Environment Research.

Permanent/permanence Assurance that a greenhouse gas emissions reduction that occurs has a durable effect over a time period that is meaningful from the perspective of addressing climate change (i.e., that it is effectively "permanent" or will remain stored and not be released for an agreed-upon time period, called the permanence period in this report).

Precision The repeatability of measurement. Precision does not require someone to know the correct or true value. If each day for several years a clock reads exactly 10:17 AM when the sun is at the zenith, this clock is very precise. The Complications of edges of time zones do not need to be considered to decide that this is a good clock. The true meaning of noon is not important because it is only important that the clock is giving a repeatable result.

Process-based (mechanistic) models Used to measure changes in greenhouse gas emissions that link important biogeochemical processes that control the production, consumption, and emissions of greenhouse gases.

Spectroscopy The use of light, sound, or particle emission to study matter. The emissions are, in many cases, able to provide information about the properties of the matter under investigation. The device often used for such analysis is a spectrometer, which records the spectrum of light emitted (or absorbed) by a given material, especially in analytical chemistry and physical chemistry fields, where the light can be used to determine the chemical composition of a substance because of signature spectral lines emitted by known elements.

Sequester To remove CO2 emissions from the atmosphere and store them in a biological or geological reservoir.

Sink Any process, activity, or mechanism that removes a GHG from the atmosphere.

Source Any process or activity that releases a GHG into the atmosphere.

Term offset credits Credits that exist for only a certain, predetermined period of time (i.e., are "temporary") and that only require that the carbon storage practices be kept in place for this term or predetermined period of time.

Uncertainty For a measured value, an interval around that value such that any repetition of the measurement will produce a new result that lies within this interval. This uncertainty interval is assigned by the experimenter following established principles of uncertainty estimation. One of the goals of this document is to help a person become proficient at assigning and working with uncertainty intervals. Uncertainty, rather than error, is the important term to the working scientist.

U.S. National Agricultural Census A comprehensive summary of agricultural activity conducted by the U.S. Department of Agriculture and provided for the United States as a whole as well as for each of the 50 states and for every county or county-equivalent. The census report includes number of farms by size and type, inventory and values for crops and livestock, operator characteristics, and much more.

U.S. National Emissions Inventory An annual estimate of U.S. anthropogenic greenhouse gas emissions and sinks for several years. The emission estimates are presented on both a full molecular mass basis and on a global warming potential–weighted basis in order to show the relative contribution of each gas to global average radiative forcing. Signatories to the U.N. Framework Convention on Climate Change, which includes the United States, must annually provide the convention's secretariat with these inventories of anthropogenic emissions by sources and removals by sinks of all greenhouse gases not controlled by the Montreal Protocol, using comparable methodologies.

Verifiable The concept that offset credits can be double-checked by independent third parties. This requires that sufficient evidence is collected and documented so that buyers and third parties can verify the volume of carbon credits issued.

Annex. Current Protocols and Permanence

FEATURE	Voluntary Carbon Standard (VCS)	Chicago Climate Exchange (CCX) [5]	Climate Action Reserve (CAR)	American Carbon Registry (ACR)[6]	Alberta Offset System
Definition of Reversal	To-date project emissions exceed baseline, or Removals from sequestration less than the baseline scenario	Cessation of best-in-class activity as defined in project specification, in whole or in part, during contracted crediting period	Difference between onsite project C stock and baseline C stock decreases from one year to next Project C stock < baseline C stock (project is terminated)	GHG reductions or removals may be reversed when a project has exposure to risk factors, including those that are unintentional (e.g., fire, flood, insect infestation, etc.) and those that are intentional (e.g., landowners choosing to discontinue project activities)	Tillage events—reversals are contemplated as linear, in keeping with the process-based modeled coefficients for sequestration
Remedy for Intentional Reversal	No future credits issued If credits have previously been issued, credits equivalent to the excess emissions or reduced sequestration are cancelled from Pooled Buffer Account	Contract cancellation Complete recovery of credits issued within term of the project-crediting period	If difference between onsite project C stock and baseline C carbon stock decreases from one year to next (due to willful act or negligence), owner must retire forest project CRTs equivalent to the decrease If onsite project C stock falls below baseline, project terminated and owner must submit forest project CRTs = total issued over prior 100 years(+ 0–40% penalty for IFM)	ACR will retire from the buffer pool the number of ERTs issued from the start date up to the time of the intentional reversal Project Proponent is required to deposit ERTs equal to those retired; deposit may be made in ERTs of any type and vintage For aggregated projects: retire and replacement requirement applies only to those landowners who intentionally reverse, not to project overall; however, Project Proponent is required to re-calculate and re-verify baseline Timber harvest included in the Project Plan is not considered an intentional reversal	No credits awarded that year No reversal of credits required: Assurance Factor accounts for reversal events across the years, so there is no additional liability Reversals come out of the Reserve Account set up by the Assurance Factor

Key to Table acronyms that do not appear elsewhere in report:

AFOLU	agriculture, forestry, and other land uses
ALM	agriculture land management
AR	afforestation/reforestation
COI	conflict of interest
CRT	climate reserve tons
E&O	errors and omissions
ERT	emission reduction tons
IFM	improved forest management
VCU	voluntary carbon unit

5 Applicable to the following agricultural carbon sequestration project types: continuous conservation tillage, grassland conversion, and sustainably managed rangeland; certain other project types, such as agricultural methane collection and combustion, are not susceptible to permanence risk and are therefore not referenced in this table

6 Applicable only to projects with an inherent reversal risk—i.e., terrestrial and geologic sequestration projects

FEATURE	VCS	CCX	CAR	ACR	Alberta
Remedy for Unintentional Reversal	Same as Intentional Reversal	Remedy ranges depending on severity of departure from project specification and can range from no credits being issued for slight departure to full cancellation and recovery for significant departure (for example: where an enrolled project field is too wet to plant and grow an annual crop during the term of a no-till contract, no credits are issued for one annual cycle, this being a slight departure from the continuous conservation tillage project specification; where project field is sold and the new land manager tills the parcel, the contract is cancelled with full recovery from the original project owner)	If difference between project and baseline onsite carbon stock decreases from one year to next (NOT due to willful act or negligence on part of owner), then CAR retires CRTs from collective Buffer Pool If onsite project C stock falls below baseline C stock at any point (NOT due to willful act or negligence on part of owner), CAR retires CRTs = total issued over prior 100 years	ACR retires from the buffer pool the number of ERTs necessary to mitigate the reversal, based on a post-reversal carbon stock assessment If the number of ERTs retired to mitigate the reversal exceeds the number of buffer ERTs deposited to date by the Proponent, this difference will come from other tons in the buffer pool, spreading reversal risk across all contributing projects Following a reversal the project's risk will be reassessed	Same as Intentional Reversal
Buffer Reserve	A percentage of credits will be held in a Pooled Buffer Account, based on a determination of the risk rating Buffer values and risk criteria are adjusted at least every 10 years based on re-assessment of risk, a review of verification reports, and common characteristics of failed or underperforming projects Minimum buffer values are conservatively estimated and should be sufficient to ensure that the balance of credits in the pooled buffer account is never negative; therefore, VCUs issued to projects that subsequently fail are not cancelled and do not have to be paid back	For soil and biomass carbon projects, 20% of registered credits are held in reserve during the term of the project crediting period	Buffer pool only intended to address unintentional reversals All tons contributed held in pooled account	Based on the results of a project-specific risk assessment, Project Proponent must contribute ERTs to a buffer pool managed by ACR, either from the project itself or ERTs of any other type and vintage (unless Proponent elects to use another approved risk mitigation mechanism) The risk category and buffer contribution percentage remain unchanged for five years, at which point risk may be re-assessed as part of a full verification, and the required buffer percentage may increase or decrease. In the event of a reversal the project baseline, risk level and buffer contribution (if applicable) will be re-assessed immediately ACR has sole management and operational control over the offsets in the ACR buffer pool	Alberta Tillage Projects are subject to an assurance factor that discounts emissions reductions related to soil organic carbon All discounted emission reductions are immediately retired to the environment and held in a reserve account that is not returned to the project developer but is held by the government to cover future reversals

FEATURE	VCS	CCX	CAR	ACR	Alberta
Determination of Risk Rating %	Contribution to Buffer Pool determined by Risk Class. To determine the overall non-permanence risk classification, all risk factors (rated fail, high, med, or low) relevant to the project are weighed up together. The overall risk class (high, med, or low) determines the buffer withholding percentage ALM risk factors: • Ownership type & land tenure • Unproven technologies & practices • Changes in net financial returns because of displaced or avoided commodity production or increased costs due to project • Frequency of crop failure from severe drought or disease • Project longevity • Generic risk factors • Project risk • Economic risk • Regulatory & social risk • Natural disturbance risk • Alternatively, projects may use the Likelihood x Significance tool: Risk (R) = Likelihood (L) x Significance (S) for each risk factor, adjusted based on scores for adequacy of Countermeasures (C) and Management system (M).[R = L x S x (1-(C x M)/16)10] • Likelihood = inverse of average number of times event has occurred over period equivalent to project lifespan, or score between 0 and 1 if no historical records are available • Significance, if quantitative = damage to project if event occurs, expressed as percentage of credits (tons lost x likelihood x number of years loss would continue) or score for degree of impact (1 to 3) • Significance, if qualitative = relative risk rating 0–3 • Risk Mitigation score, 0–4 • Risk Mitigation Management System score, 0–4	20% for all terrestrial projects applied to crediting rate (implicit reserve)	Contribution to Buffer Pool determined by Risk Rating: • Financial risk = 1.5% if no easement • Mgmt risk, illegal removal = 0% in US • Mgmt risk, conversion = 3% if no easement • Mgmt risk, over-harvest = 3% if no easement • Social risk = 3% or 2% w/easement • Natural disturbance, fire = annualized risk % (based on 30 year history for Assessment Area or Project Area if available) x discount for fuel treatments • Natural disturbance, disease/insect = 3% or 2% w/easement • Natural disturbance, wind = 3% or 2% w/easement • Overall Risk Rating = 100% - (1-Finanical Risk %) x (1-illegal logging %) x etc.	Project-specific risk assessment, including general and project risk factors, conducted by Proponent and evaluated by ACR and verifier Assessment is conducted using the ACR risk tool (pending release of this tool, Proponents may use the VCS tool for risk analysis and buffer determination) General risk factors include financial failure, technical failure, management failure, rising land opportunity costs, regulatory and social instability, and natural disturbances. Project-specific risk factors vary by project type but for forestry include land tenure, technical capability and experience of the project developer, fire potential, and the risks of insect/disease, flooding and extreme weather events, illegal logging potential, and others	Permanence Assurance Factor intended to account for the average risk of reversal across all farms within a given region Risk assessment based on historical incidence of reversals over the last 10 years As the sequestration of carbon over time is linearized, reversals are assumed to be equivalent in magnitude. As such, the Assurance Factor could then be estimated using the following formula: Assurance Factor = (1 - (# of Reversal Events / 20 year period)) * 100%

FEATURE	VCS	CCX	CAR	ACR	Alberta
Application of Risk Rating	Risk rating scores are converted to risk classification: fail, high, medium, or low. Credits to be withheld are based on default buffer withholding percentages for each project type as follows: • ALM Improved Cropland Management • High 30–60% • Medium 15–30% • Low 10–15% • ALM Improved Grassland Management • High 25–50% • Medium 15–25% • Low 10–15% • ALM Cropland & Grassland Conversions • High 25–50% • Medium 15–25% • Low 10–15%	N/A	Risk Rating x total CRTs issued	Overall risk category that results from assessment of general and project-specific risks is translated into a percentage of ERTs that must be deposited in the Buffer Pool (unless Proponent elects another approved risk mitigation mechanism) Buffer contribution may be made in ERTs from the project itself, or ERTs of another type and vintage	Sequestered soil organic carbon is calculated by applying regionally modeled coefficients (which are specific to either no-till or reduced-till activities) Regionally specific assurance factor is applied to emission reductions associated with soil organic carbon only
Buffer Reserve Recovery	Optional verification of VCUs generated in the past, prior to the expiration of the crediting period If the risk rating remains the same or decreases from one verification event to the next, every five years upon verification, 15% of the total buffer reserve (including newly deposited credits) are released and made available for trading	Project owner recovers 100% of tons placed in buffer reserve following contract expiration	Risk rating is reevaluated at each verification; CAR may allow recovery based on future reevaluation of risk factors	Buffer ERTs not used to compensate for a reversal will be refunded over time to the Project Proponent, at the rate of 5% for each five-year interval at which the project undergoes a full verification. Any buffer ERTs that have not been retired or refunded by the end of a project's term will be retained and retired by ACR	No recovery allowed

FEATURE	VCS	CCX	CAR	ACR	Alberta
Other (Non-Buffer Reserve) Options	None	None	CAR to evaluate other options such as third party insurance in future	ACR-approved insurance mechanism, which guarantees replacement value of the offsets lost in the case of a partial or complete reversal, with no hidden costs or exclusions ACR conducts due diligence on all insurance mechanisms proposed by Proponents	N/A
Crediting Period	Minimum of 20 to maximum of 100 years; 20 years is considered the minimum acceptable AFOLU project crediting period for the buffer approach to serve as an effective non-permanence risk mitigation For ALM projects that focus exclusively on reduction of N2O, CH4, and/or fossil-fuel-derived CO2 emissions; the maximum is 10 years, renewable two times	Crediting period for soil projects is five years (future years; year one is year contract is signed) with unlimited five-year extensions Crediting period for biomass (afforestation) is 15 years Other project types (such as methane destruction) do not require a specific contract length; however, offsets are issued retroactively	CRTs issued up to 100 years following start date	Crediting period for AR and IFM projects (except stop-logging) is 25 years, with opportunity for renewal Crediting period for REDD/stop-logging IFM projects is 10 years, with opportunity for renewal	Alberta Tillage projects are eligible to generate credits for 20 years following the project start date Monitoring and verification must continue for as long as the project continues to claim emission reductions
Permanence Period (commitment period for monitoring and reporting on any reversals)	The number of buffer credits that a given project must deposit into the AFOLU Pooled Buffer Account is based on an assessment of the project's potential for future carbon loss as well; there is a "true-up period" every five years to ensure enough credits are in the account for the future, based on the projects performance	Same as crediting period	Monitoring/verification must continue 100 years following last issuance of CRT	ACR has proposed a minimum term of 50 years for forest carbon projects, beginning on the project start date; this is still pending the results of public consultation and scientific peer review At the end of the minimum term, if the Proponent does not renew for another crediting period and continue monitoring and verification, ACR conservatively assumes that the project activities have ceased and retires remaining buffer tons If Proponent does not renew crediting period but does continue to maintain the project, Proponent may provide documentation of continuance (e.g., satellite imagery); no ERTs will be issued, but with documented continuance and no reversals, ACR will continue scheduled refund of buffer ERTs	The minimum time commitment is expected to be 25 years after the last ton sequestered by the project; the reserve account will be in place for the government to account for any future reversals over this period The 25 years is set in Draft Government of Canada Offset System rules, pending approval Alberta will likely align with federal rules

FEATURE	VCS	CCX	CAR	ACR	Alberta
Periodic Monitoring/ Reporting Requirement	A monitoring plan is required as part of project design, and is subject to the verification process	Ongoing monitoring throughout project contract period	Monitoring reports must be submitted at least once every six years Monitoring reports must be "overseen" by professional forester Must monitor and verify for 100 years following issuance of last CRT (i.e., 200 years), unless commitment ends with early termination for: Natural significant disturbance leading to unavoidable reversal that reduces standing live carbon below baseline Voluntary termination if owner retires forest project CRTs = total issued from start date (+ IFM penalty)	ACR requires a measurement and monitoring plan as part of GHG Project Plan At each issuance of ERTs, Project Proponent must submit Attestation Letter addressing actions, additionality, ownership, permanence, and net positive community and environmental impacts Verification required for issuance of ERTs	Verification and project reports are only required when claiming emissions reductions No monitoring required past the credit duration period Changes in land use will be picked up by National Inventory, in system-wide true up accounting
Periodic Verification Requirement	Verification (an on-site verification and a desk review) is required prior to issuance of VCUs. Market leakage assessments and AFOLU non-permanence risk assessments are subject to the double approval process. If no verification report is submitted within five years of the previous verification, 50% of the credits in the buffer are cancelled; after 10 years, all credits in the buffer pool are cancelled; after 15 years, if no subsequent verification has been presented and the crediting period has not expired, buffer credits are cancelled from the pooled buffer account for an amount equivalent to the total number of VCUs previously issued. However, cancelled credits can be claimed by submitting a verification report prior to the end of the crediting period.	Both on-site and desk annually Pooled projects (soil, biomass) may utilize representative sampling protocols	On-site verification required initially and at least every six years Not required to re-inventory, but must sample to confirm growth/harvest projections still accurate Desk verification required for optional annual monitoring report (non-site visit)	Independent, third-party verification by an ACR-approved verifier is required prior to any issuance of ERTs At each request for issuance of new ERTs (usually annually, but may be more or less frequent at Project Proponent's request), Project Proponents must submit a verification statement from an approved verifier based on a desk audit At least once every five years, Proponents must submit a verification statement based on verification, including a field visit to the project site and such measurements as the verifier requires in order to verify Verification is also required in order to renew a project's crediting period	Verification reports are required when claiming emissions reductions (can be annually or any other period as per the discretion of the project proponent)

FEATURE	VCS	CCX	CAR	ACR	Alberta
Verifier Qualification	Verifiers for ALM projects must be accredited for sectoral scope 14of ISO 14065 under an approved GHG program (e.g., CDM), or by an accreditation body that is a member of the International Accreditation Forum (e.g., American National Standards Institute, ANSI), or under the VCS temporary accreditation program	Minimum verifier requirements: • Verifier must carry project-specific E&O insurance for $2 million • Verifier must demonstrate technical competence for each project type they wish to become approved to verify • Verification company must demonstrate corporate experience through references • Verifier must submit project-specific COI for each verification term • CCX has worked with ANSI to audit ISO 14064 and ISO 14065 and develop an ANSI Certification Program for each project type; beginning in 2010, ANSI certification will be required for each project type	Key requirements: • Accredited by ANSI under ISO 14065 • Meet the Reserve's sector-specific accreditation requirements • Demonstrate a thorough understanding of the Climate Action Reserve Project and Verification Protocols • Have a minimum of two staff members designated as Lead Verifiers • Lead Verifiers are required to have completed Reserve training on its project protocols, specific to the sector that the Verification Body is accredited under • Must sign NOVA/COI form for each project verification • Professional indemnity insurance to the level of at least $1,000,000	Verifiers for ACR shall be accredited under the applicable sectoral scope following ISO 14065:2007 and they must be: • Accredited and in good standing by an approved GHG program (CDM or JI) • Accredited and in good standing with ANSI; or • Approved under the ACR interim verifier approval process.	Verification Standards: • ISO 14064 Part 3 – Greenhouse Gases: Specification with guidance for the validation and verification of greenhouse gas assertions • Standards for Assurance Engagements, Canadian Institute of Chartered Accountants Handbook – Assurance Section 5025 • International Standards on Assurance Engagements (ISAE) 3000 - Assurance Engagements Other Than Audits or Reviews of Historical Financial Information • Lead verifier must be either a Chartered Accountant or a registered Professional Engineer
Contract Structure and Content	Not specified	Terms of the contract are left to the discretion of the parties; however contract must ensure that all project protocols are met including but not limited to project implementation, project management, periodic reporting, verification, and accountability of all parties	Project Implementation Agreement (PIA) must be signed committing owner to maintain monitoring/verification, notify CAR of property transfer and have new owner sign PIA, submit CRTs for intentional (willful or negligent) reversal or voluntary termination	The ACR member agreement is the governing legal document detailing rights and responsibilities of ACR and its members (including Project Proponents) For forest Project Proponents electing the buffer pool for risk mitigation, ACR and the Proponent will enter into a legal agreement governing buffer contributions and retirements ACR does not enter into any contract or agreement with landowner(s), except in the case where the landowner and Project Proponent are the same	Not specified

Endnotes

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[xxxiv] Lal, op. cit. note 31.

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