Agricultural Soil Carbon Sequestration: Economic Issues and Research Needs

Draft paper

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Agricultural Soil Carbon Sequestration
Economic Issues and Research Needs

1 Introduction

Society is beginning to focus attention on the potential problems of climate change and their possible mitigation through reduction of net greenhouse gas emissions (GHGE) into the atmosphere. One of the principal greenhouse gasses (GHG) is carbon dioxide. While man releases carbon dioxide into the air through many mechanisms, one of the largest of these is through energy consumption - principally combustion of fossil fuels. Thus, primary options for net GHG management include energy use reduction or energy production fuel source switching.

However, options exist which may avoid the need for drastic and potentially expensive shifts in energy use and production. Atmospheric carbon dioxide and any increments thereto become part of the global carbon cycle. Annually that cycle involves processes where more than 20 times the current level of anthropogenic emissions of carbon are emitted or absorbed by the terrestrial ecosystem each year (Schlesinger(1995)). Estimates are that about 80 per cent of global carbon is stored in the soil component of this ecosystem (Watson et al, 2000, p. 4). Furthermore it is known that a substantial proportion of carbon that was originally in soils has been released due to human land use, principally cultivation (Lal et at 1998). Collectively, the flux of carbon through the terrestrial ecosystem, and the current degraded state of soils have been argued as indicators of a major opportunity to reduce net GHGEs by increasing retention or sequestration of carbon in soils.

Sequestration of atmospheric carbon in agricultural soils has become a topic of substantial interest within the agricultural community. The interest is largely stimulated by the prospect that a market or subsidy program might arise wherein producers could be paid to increase the carbon content of their soils. This interest is beginning to stimulate policy action with bills being introduced in Congress and discussions in both environmental and agricultural agencies regarding potential policy and/or program design. Furthermore President Bush recently released a “Global Climate Change Policy Book” which identifies and 18% net GHGE reduction goal over the next 10 years and says “The President's FY '03 budget requests over $3 billion - a $1 billion increase above the baseline – as the first part of a ten year (2002-2011) commitment to implement and improve the conservation title of the Farm Bill, which will significantly enhance the natural storage of carbon. The President also directed the Secretary of Agriculture to provide recommendations for further, targeted incentives aimed at forest and agricultural sequestration of greenhouse gases. The President further directed the Secretary of Agriculture, in consultation with the Environmental Protection Agency and the Department of Energy, to develop accounting rules and guidelines for crediting sequestration projects, taking into account emerging domestic and international approaches.”

There are a large number of factors which need to be considered in setting up appropriate soil carbon sequestration oriented policy and programs. A substantial literature is emerging regarding soil science and computer simulation modeling aspects of carbon sequestration (see the books by Lal et al(1998), and Follett et al(2000) as well as the Intergovernmental Panel on Climate Change (IPCC) Land Use Report (2000)). However, a comprehensive and unified treatment of the economic aspects of the issue has not emerged. This paper overviews economic issues involved with the pursuit of agricultural carbon sequestration (ACS) principally in soils. Then we present a brief discussion on what we know and need to find out from a research perspective. Before addressing those topics we present an economics and policy oriented discussion on why it might be desirable to promote ACS in the U.S. or elsewhere.

2 Why Consider Promoting Agricultural Soil Carbon Sequestration?

ACS while being a long-standing concern of the soil science community, has recently evolved into a broader concern across the agricultural and resource communities. The reason for the expanded concern arises from a combination of eight principal forces. Namely concerns about:

- Greenhouse gas forcing and climate change,
- International agreements as manifest in the Kyoto Protocol,
- International pressures on emissions,
- Domestic policies directed toward pollution,
- Industry planning under uncertainty,
- Need for cheap emission offsets,
- Congruence of ACS with other agriculturally related societal desires such as farm income support and water quality protection, and
- Development of another market for farm products

Each of these will be briefly and individually examined, but it appears clear that a combination of these factors will be involved in the emergence of any ACS program.

2.1 Greenhouse Gas Forcing and Climate Change

In the recent past, substantial scientific endeavor has been directed toward understanding and forecasting the linkage between GHGEs, climate change, and economic activity. The IPCC scientific based assessments, as they have arisen over time, report an ever-growing consensus scientific opinion that in the foreseeable future increasing concentrations of GHGs will cause a substantial degree of climate warming. Atmospheric concentrations of carbon dioxide, the most abundant GHG, are forecast to double by the end of the 21st century. Such large concentrations coupled with increases in other GHGs are predicted to cause substantial rises in global temperatures (by 1.5 to 6 degrees Centigrade - Watson (2000) elaborates) along with accompanying alterations in precipitation patterns.

Numerous scientific efforts have tried to predict the impact of such a climate shift. Predictions to date suggest GHG concentration increases will alter economic and environmental attributes of agriculture, forestry, energy, human diseases, coastal resources, ecosystems, and water availability among many other impact categories. Recent broad based assessments or literature reviews regarding potential climatic change impacts appear in the IPCC documents (1990, 1996, 2000, 2001); and the recent U.S. Global Climate Change Research Program National Assessment Report (2000). Agriculturally oriented material appears in the sources cited above plus the reviews and analyses in Adams, Hurd and Reilly (1999); Lewandrowski and Schimmelpfennig(1999); McCarl, Adams and Hurd (2001); Joyce et al (2000); Irland et al (2001), and Reilly et al(2000, 2001a, b)). Nevertheless, there remains substantial uncertainty about climate change impacts.

One way to partially avoid prospective climate change or climate change risk is by reducing the amount of GHGs in the atmosphere. The IPCC documents present compelling arguments that, while it will be a long time before we know the exact effects of climate change, future reductions in GHG concentrations will take a very long time to achieve and that perhaps as a precautionary move we should begin reduction efforts now. The increase in atmospheric GHG concentrations is largely caused by rising emissions from a diverse set of sources including emissions from fossil fuel combustion, deforestation, agricultural land use changes and land degradation. A reduction in the rate of GHGEs would reduce future atmospheric concentrations. In addition, and of key importance to the topic of this paper, the IPCC and others have pointed out that society could also enhance absorption of carbon from the atmosphere and store (sequester) it somewhere in a sink. Increasing the organic content of soils by enhancing the biological fixation of carbon into the soil is one of the sequestration possibilities.

Thus, the first reason for pursuit of ACS is that sequestration can absorb GHGs from the atmosphere and can help reduce future deleterious effects of climate change. Such actions may be motivated either by:

- a genuine belief that GHGE induced climate change will bring about future negative effects or
- adoption of a precautionary principal that it is desirable to slow down potential GHGE forcing of climate change and preserve societal options motivated by the uncertainties involved with GHGE forcing.

2.2 Compliance with International Agreements

The U.S., along with most of the developed world, is a member of the United Nations Framework Convention on Climate Change (UNFCCC), which has the stated objective of stabilizing atmospheric GHG concentrations. The U.S. is also among the signatories to the UNFCCC generated international agreement called the Kyoto Protocol (KP), which mandates actions reducing GHGEs. However the reader should note Congress has not ratified the KP and recent Presidential pronouncements make it likely that the U.S. will not be part of at least the first commitment period.

If fully ratified, the KP requires that the U.S. achieve a seven percent reduction in net GHGEs relative to 1990 levels by a 2008-2012 commitment period (see Reilly (1999); or

Marland, McCarl, and Schneider (1998, 2001) for agriculturally based discussions of the terms within the agreement). The effective required GHGE cut as of the commitment period is larger than seven percent considering the growth in emissions that will or would occur between 1990 and the commitment period. Considering likely growth levels, the emissions reduction rises to roughly a fifteen percent cut in anticipated net GHGEs as of the commitment period in the absence of any reduction effort.

The parties to the KP are involved in active international initiations regarding implementation details. A notable KP feature is the explicit allowance for emission offsets through sinks including forestry related activities (section 3.3) and the possibility of using agricultural soils (section 3.4). The 2000-2001 negotiations heavily focused on sink issues and as of the COP 7 meeting in Marrakech in late 2001, strongly indicate that agricultural sinks will be permissible.

Thus, a second substantial reason for the interest in ACS involves the role of ACS in meeting international agreements regarding net GHGEs reductions.

2.3 International attitudes toward U.S. emission levels

Internationally, concern is high and on the rise in regard to climate change and GHGE climate change forcing. This is certainly evident in the European Union (EU) as illustrated by the leading role played by a number of EU countries in KP related negotiations and the failure to reach an agreement on sinks in the November 2000 UNFCCC COP-6 meeting. That failure arose in part due to EU desires that the U.S. rely more on emissions reductions and less on sink based strategies. These developments indicate that the U.S. is likely to be under substantial international pressure to reduce net emissions regardless of whether agreements like the KP are ever congressionally ratified.

Thus, the third major motivation for interest in ACS is the desire to reduce net emissions in order to facilitate international relations.

Domestic Pollution Related Policy The current U.S. President (George W. Bush) ran for office with a campaign plank involving control of electric power plant emissions of four pollutants: sulfur oxides (SOX), nitrous oxides (NOX), mercury and carbon dioxide. Events by mid 2001 involving electrical energy supply and industry pressures brought about a Presidential pronouncement that the regulation would be scaled back and would not cover carbon dioxide emissions in the near future. However versions of the four pollutants regulation continue to be discussed in Congress and individual states have discussed or implemented carbon dioxide related legislation. Furthermore President Bush’s February 2002, Global Climate Change Policy Book indicates a goal to “Reduce the greenhouse gas intensity of the U.S. economy by 18 percent in the next ten years”**.**

Thus the fourth major motivation for ACS interest involves it's potential as a way of meeting future domestic policy requirements.

2.4 Industry Planning in the Face of Uncertainty

Industry in the U.S. is faced with an uncertainty today as to whether greenhouse gas emission limits will be imposed in the next 10-20 years. Multinational corporations (which are common in the energy component of industry as well as in the other emitting sectors) face a higher degree of certainty of emission caps for operations in Europe and other parts of the industrialized world.

This uncertainty places a large part of business assets at risk. For example, assuming that an eventual cap of 7% below 1990 levels is imposed and that energy use growth continues until the time that the cap is imposed, it is not unreasonable to think that industry faces a substantial chance of needing to operate in a word where by 2010 emissions need to be 15% or so smaller than they would have been. Assuming that the emissions are proportional to total output this would put at risk 15% of gross sales, facilities etc.

The magnitude of the risk caused by possible implementation of GHGE limits has drawn industry attention. Many firms have started the quest to discover and even begin implementation of ways to reduce GHGE in an economically sound manner. Virtually all petrochemical, and electric power generating firms now have offices with titles involving climate change or greenhouse gas emissions charged with trying to develop, and sort out an array of possible business responses for GHGE management. Sequestration is a major option on the table.

Thus, the fifth major motivation for ACS interest involves its potential as a way that businesses may hedge against future deleterious impacts of domestic or international emission caps.

2.5 Need for cheap emission offsets

The above reasons for ACS interest involve considerations that would cause emitters in the U.S. to reduce net GHGEs via choices from a broad set of emission reduction and offset alternatives. Such forces do not necessarily favor ACS. Rather any emission reduction possibility will do.

However, focused interest on ACS alternatives has arisen because of anticipated relatively low ACS per tonne carbon cost[1] and a feeling that adjustments can be made in a relatively short time frame. A number of ACS related strategies are currently in use by agricultural producers acting in their own self-interest without any GHGE related program in place. Furthermore, many of the strategies for changing ACS involve existing, well-known technologies which could be adopted in the near term as opposed to a number of non-ACS strategies which require costly and time-consuming technological innovation and/or engineering efforts to reduce implementation costs.

Thus, a sixth motivation for interest in ACS and involves the potential that ACS practices may be relatively inexpensive ways of making a difference in net GHGEs in a timely fashion.

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[1] Here and throughout the rest of the paper we will discuss the carbon volume in metric tonnes or tonnes.

2.6 Linkage to other goals for agriculture and environmental impacts

Many of the potential ACS practices have been previously encouraged in U.S. government farm programs designed to achieve environmental improvements and agricultural income support. Conservation incentives involving reduced tillage have been present in recent agricultural farm bills and have been justified on the basis of environmental improvement and agricultural income support. Conservation programs and many of the ACS practices both involve direct support payments to farmers and have supply control characteristics which tend to lower aggregate production and raise market prices both contributing to farm income enhancement (McCarl and Schneider, 2001). Water quality and soil erosion programs have also been undertaken to encourage practices which change tillage intensity and land use, retire fragile crop plants to grass or trees, preserve or re-establish wetlands, improve wildlife habitats and provide chemical and erosion retaining stream buffers. Such practices also increase soil carbon along with decreases in such varied items as nitrogen runoff, soil erosion and other chemical use (McCarl and Schneider (2001), Plantinga and Wu(2002) and Bondelid et al(2001)). Furthermore, a number of the soil carbon retaining possibilities increase soil quality enhancing nutrient and water retention and possibly stimulating yield increases. Thus, a number of the strategies, which increase ACS, have positive co-benefits such as farm income support, farm productivity enhancement, and environmental quality improvement.

The seventh motivation for ACS interest involves the congruence of an ACS program with other policy goals and the existence of co-benefits. These interests are exhibited both domestically within the U.S. and internationally particularly in developing country environments.

2.7 Development of another Market for Farm Products

The above motivations largely cover factors, which stimulate action or concern on the behalf of general society and policymakers. Agricultural producers are also interested. The KP allows for an emissions trading market whereby producers employing ACS strategies could sell GHGE offset credits to those in need of GHGE reductions or rights (see Sandor and Skees(1999) for discussion). In particular, a carbon market much like the sulfur dioxide market might arise (See the various papers in Kosobud (2000)). By gaining rights to sell GHGE offsets through the use of ACS practices, agricultural producers would gain income-enhancing opportunities.

Simultaneously, industrial concerns are interested because ACS practices may provide cheaper net GHGE offsets than those they can generate within their business. For example by promoting ACS, an electric utility might be able to avoid making large investments to directly capture and store carbon dioxide in favor of cheaper ACS activities.

Thus, the eighth and final motivation covered herein for ACS interest involves potential participation in the income enhancing and cost reducing features of an emissions trading market.

3 Economics of Programs Promoting Agricultural Soil Carbon Sequestration

There are numerous economic considerations involved in developing an appropriate ACS strategy regarding net GHGE reduction. For presentation purposes, we group these considerations under four main, not entirely independent, questions.

- What is the cost of GHGE offsets arising from large-scale implementation of ACS across the agricultural landscape?
- What are the economic implications of mechanisms that can be used to contract for, monitor and verify ACS activities?
- How desirable are ACS related strategies in comparison with other strategies for reducing net GHGEs?
- What are the policy pitfalls and possible implementation directions for ACS policy?

3.1 What is the cost of GHGE offsets arising from large-scale implementation?

A primary implementation concern involves the cost of employing ACS strategies to create GHGE offsets. This is basically a production economics question: how much of an economic incentive will farmers need to induce them to modify land use and management practices so as to sequester and store additional soil C? We again divide the topic, addressing it through a series of sub questions

- What practices can be employed to sequester carbon?
- What is the cost of getting a practice put into place?
- What is the economic cost of emission reduction?
- How do we measure the GHGE offset quantity?
- What is nature of the cost relationship in involved with the GHGE offsets?
- How might dynamics, volatility and saturation affect program design?
- How does one compare GHGE alterations at different points in time?
- Does the aggregate quantity of GHGEs offset equal the quantity offset by a project -- Does leakage occur?
- Are there other valuable co-benefits from ACS activities?
- How are GHGE offsets affected by climate change?

3.1.1 What practices can be employed to sequester carbon?

There are two major types of actions that can be employed to pursue ACS. These involve practices, which change the way land is managed and practices, which involve changes in, land use.

3.1.1.1 Changes in Land Management

Agricultural management can be changed to enhance ACS. The most commonly discussed management changes involve tillage, nutrient and residue management and involve reductions in tillage intensity (adopting conservation tillage or no-till), adding organic manure, altering fertilization and/or somehow leaving behind more crop residues. Strategies have also been mentioned which involve changing rotations, altering crop mixes, employing more perennials, growing crops with more above ground biomass, using winter cover crops, and utilizing erosion control techniques such as terracing, contour plowing, strip cropping, buffer strips, and water management. (Lal et al(1998) cover the crop lands topic in much more detail).

ACS can also be stimulated by changes in pasture and rangeland management which involve altering plant species on pasture lands, improving grass productivity, reducing grazing intensity, employing fertilization, or otherwise altering management so as increase the amount of organic manner incorporated into the soil. (Follett et al (2000) cover the grazing lands topic in much more detail).

3.1.1.2 Changes in Land Use

Carbon sequestration may also be increased by changing land use. Generally uses that disturb the soil less often enhance sequestration. Thus, the strategies that have been prominently discussed include

- Conversion of croplands to forestry, grasslands, pasture, rangelands or wetlands.
- Conversion of pastures or range to forestry.
- Restoration of degraded lands, in an effort to reestablish their organic content.

3.1.2 What is the cost of getting a practice put into place?

Fundamentally, while policymakers and other interests may desire that particular ACS enhancing practices be put into place, they cannot directly control this. Rather, the farmer or rancher controls the practices employed on a piece of ground. Farmers and ranchers use the practices that are best from the standpoint of their well-being. Well-being is a complex consideration involving many dimensions including:

- Profitability of the practice,
- Amount of risk borne when employing the practice,
- Time availability of resources required to use the practice,
- Amount of training and/or learning required to employ the practice,
- Willingness to adopt the degree of management required to employ the practice,
- Consistency of the practice with the existing equipment complement
- Needed level of investment to change over plus condition of equipment that needs to be changed in terms of time to replacement and capital availability,

- Desire for environmental stewardship coupled with the environmental attributes of practice, and
- Need to comply with government regulations.

In some cases, farmers use practices that contribute to ACS because they have already judged those practices superior to the alternatives. However, in other cases, practices that could increase ACS are not being used. When these ACS-enhancing practices are not being used, incentives are needed. This may involve direct incentives in the form of payments for practices or payments for carbon accumulation. In addition, indirect incentives may be used such as conservation incentives for ACS practices, crop yield insurance, sequestration shortfall insurance, investment subsidies, or training programs.

For example, consider the adoption of no-till farming practices as opposed to conventional moldboard plowing. According to discussions with farmers (see the comments of Bennett (1999)) it appears farmers have reservations about no-till adoption which involve such diverse factors as

- Potential yield alterations,
- Potential increases in cost particularly for weed and insect control,
- Need to acquire new expensive equipment,
- Critical reliance on the efficacy of chemical weed control compounds and the need for continued efficacy into the future of weed control methods (the lack of development of weed resistance to control methods),
- Learning time to effectively employ the practice,
- Willingness on behalf of older farmers to switch practices, and
- Potential yield variability increases due to factors such as slower warming of untilled soils during cool spring planting seasons and accompanying later crop germination times leading to yield losses.

The magnitude of the financial incentives required to stimulate adoption is affected by all of these factors. In cases where only changes in yields and costs are involved, a lower bound on the required incentive could be calculated. This would equal the net income lost due to any yield loss (note yield gains are possible) times price plus the net value of any cost change. However, calculations based solely on only net income loss or gain are likely to understate the incentive level needed, as other factors must also included. For example, Babcock et al (1996) indicate that nominally profitable practices may not be fully adopted. Furthermore, it has been an agricultural economic conundrum for many years as to why apparently superior reduced tillage practices are not adopted. This certainly points to the importance of factors beyond pure profitability and the need for incentives. In a study in Iowa, Kurkalova, Kling, and Zhao find a premium of $2.40 per acre per year for corn and $3.50 per acre per year for soybeans is needed to induce conservation tillage adoption beyond the economic advantage it has over conventional tillage. What is needed to judge the social desirability of an ACS practice is a measure of the magnitude of the direct payment needed to induce switching behavior for each practice plus the per acre amortized cost of any other incentives in place that affect the decision.

3.1.3 How do we estimate the GHGE offset quantity?

When it comes time to measure the offsets generated by an ACS action two sets of considerations arise the first involving the volume of carbon in soils and the second total GHG accounting.

3.1.3.1 Carbon in Soils

The primary target GHG for ACS practices is carbon dioxide as commonly measured in terms of the amount of additional carbon sequestered in the soil. The amount of carbon sequestered in a given soil by a given ACS practice is a function of the practice, soil properties, climate conditions, soil carbon content before the practice is begun and carbon potential of the soil among many other factors (Tiessen, Stewart and Bettany, 1982; Mann, 1986; Rasmussen and Parton, 1994). Furthermore, soil carbon content will not always increase when employing a given practice. For example, West et al (2000) did a meta analysis across reduced tillage experiments and found carbon sequestration increases for adoption of reduced tillage in comparison with conventional tillage in corn and soybean production systems. However West et al (2000) found a carbon sequestration decrease in a meta function for wheat production systems. In the underlying individual wheat tillage change experiments the array of studies contains results with both increased and decreased sequestration.

Carbon is more costly to measure than conventional products such as crops and livestock. Carbon cannot be directly observed, rather the carbon content of the soil must be scientifically measured. Furthermore carbon is distributed differentially across all parts of the landscape and thus measurement must account for spatial heterogeneity. Soil scientists have posed various instrumentation-based approaches to measure carbon and through repeated observations over time the change in carbon stocks. However, according to a forthcoming CAST report (Paustian et al(2001a, b)), measuring changes in soil carbon is complicated by the great amount of carbon that is relatively inactive on an annual time scale. Furthermore, that report contains arguments that changes are difficult to detect given the great amount of variability observed from year to year. To implement contracts for ACS, a scientific consensus will be needed on the most reliable and cost effective methods for measuring soil C. This will most likely involve landscape-level measurements based on sample measurements, modeling and extrapolation (Boscolo et al 2000; Brown et al 2000; Mooney et al 2002).

3.1.3.2 Total Greenhouse Gas Accounting

GHGs are not limited to carbon and carbon dioxide. Methane and nitrous oxide are also important agriculturally related GHGs. Agriculture is an important direct emitter when considering all of these GHGs (EPA 2000) generating as much as 50% of the methane and 70% of the nitrous oxide along with 7% of the carbon dioxide. Many ACS activities can alter the quantity of GHGE directly arising from agriculture. In addition, indirect

GHGEs are involved in manufacturing and transporting agricultural inputs and outputs. The volume of such emissions would be influenced by altered input use or production.

When computing net GHGE consequences of ACS practices, it is important to take a total GHGE accounting stance as opposed to a carbon sequestered only approach. The final estimate of GHG offset due to a practice is the difference between before and after levels of GHGEs. This level of GHGEs equals estimated carbon sequestration arising from simulation, experimental or other sources plus any carbon emissions avoided from fuel savings less the estimated net additional emissions from input manufacture, and any additional net nitrous oxide releases.

Alterations in methane may also occur, but that there is no recommended methodology for estimation of this, nor do we find discussion in the current literature that indicates this is a potentially important omitted factor.

Some aspects of the above paragraphs merit amplification. Namely, the sections dealing with fertilizer and fuel savings are amplified on below.

3.1.3.2.1 Indirect Emissions

An important GHGE related aspect of ACS improving practices is that they may employ emission-causing inputs such as additional nitrogen fertilizer or other petrochemicals. Consider adding nitrogen fertilizer. In such a case, Schlesinger (2000) argues that one need to account for the carbon dioxide emitted when the fertilizer is manufactured.

The IPCC Inventory And Good Practice Guidelines (1996, 2001) for emissions from fertilizer production estimates can be transformed to yield an estimate that 0.45 pounds of carbon dioxide are emitted per pound of nitrogen fertilizer manufactured. There are also substantial nitrous oxide emissions from fertilized fields due to the nitrification and denitrification of applied nitrogen. Using the IPCC Good Practice (2001b) recommended formulae for approximating these emissions basically implies that 1.25% of applied nitrogen is released as nitrous oxide in addition approximately 0.75% more arises from leaching, runoff, and ammonia volatilization loss of fertilizer N and resulting N2O production in aquatic systems off field leading to a total of approximately 2% (Mosier, 2001). Coupling this with a global warming potential of 310 and the molecular weight of carbon within carbon dioxide or 44/12, the carbon equivalent cost of nitrous oxide emissions when one pound of nitrogen fertilizer applied is 1.81 pounds of carbon. Thus, in total when additional nitrogen fertilizer is used in the ACS practice as opposed to the current practice one should estimate a carbon offset at the rate of 1.81 pounds of carbon per pound of additional nitrogen used.

3.1.3.2.2 Fertilizer and Fuel Savings

ACS stimulated net GHGE offsets should also likely reflect a credit for the emission savings arising from reduced fuel use due to practice adoption. For example, there are carbon emissions saved by lowered diesel use when using less intensive tillage. Fertilizer and other inputs may also change and in turn the emissions needed in manufacturing and marketing those items.

3.1.4 Economic cost of emission reductions

The cost of GHGE reductions produced by an ACS practice involves a marginal calculation. This marginal calculation needs to be done for both the incremental quantity of GHGE provided and the program cost. Namely, the quantity of GHGE offset including sequestration stimulated by the incentive should be computed as the difference between the offset after the ACS improving practice is adopted less the offset under the current practice in place before adoption. As discussed in the next section, this offset should be computed as the net GHGE quantity including the calculation of sequestration less any additional emissions stimulated by practice adoption. In turn, the economic cost of adoption is the total marginal financial incentive required to stimulate practice adoption including transactions costs divided by the quantity of net emission reduction. Conceptually simple, this marginal calculation is frequently overlooked by physical scientists (see the article by Schlesinger (2000) for an example).

3.1.5 Nature of the cost relationship in involved with GHGE offsets

There are important characteristics regarding the expected form of an agricultural net GHGE ACS based cost relationship. In particular, one should expect an upward sloping cost function for GHGE quantities. Namely starting at any given incentive level there will be a quantity of GHGE offsets that could be obtained and one would find that additional offsets could be obtained if one were willing to pay more for them. Such an expectation arises because of practice adoption considerations at any particular site and spatial heterogeneity across sites. Let's examine these statements using an example and evidence found in literature.

3.1.5.1 Implementing carbon sequestration programs at a site

Suppose we consider the nature of the supply curve for sequestering carbon on a single farm. For discussion purposes, suppose we focus on an example involving a hypothetical Corn Belt site employing the traditional corn, and soybean production system. Currently, the majority of Corn Belt soybean acreage is operated under a reduced tillage cropping system, while a small minority of the regional corn acreage is produced in such a fashion. A possible ACS practice for a site currently treated entirely with conventional tillage is adoption of conservation tillage. To get the producer to switch would involve incentive payments. Given the predominance of reduced tillage acreage for soybeans it would appear that a relatively low incentive payment would be needed to cause adoption of soybean reduced tillage creating a quantity of additional sequestered carbon that could be obtained at a relatively low cost. Subsequently, if more carbon were desired and the carbon incentive payment increased, then at some point the producer would switch to less intensive tillage for corn. This would likely create at least a three-step curve where at zero and very low carbon prices, no additional carbon would be supplied, then at the soybean tillage switch point an initial quantity would be supplied. Subsequently, at a somewhat higher price a corn tillage shift would occur and yet more carbon would be obtained. In practice, additional factors and decision options would cause yet more steps. For example, carbon increments and other GHGE increments could be gained due to relatively continuous potential changes in fertilization and possibly other inputs. Also lumpy changes could occur in time of planting, crop mix, crop varieties, rotations, supplemental irrigation/dryland choice, tillage changes on more minor crops, use of cover crops, and acquisition of larger equipment along with many other factors.

Antle and Mooney (2002) show that an upward sloping carbon offset supply curvecan be derived from farmers' decisions to enter into soil C contracts; Antle et al (2001a, 2001c) derive an empirical marginal cost curve for sequestration in a wheat fallow production system in Montana. Similarly, Apland, McCarl and Baker(1991) find an upward sloping cost curve of crop residue in a multi crop Corn Belt case study wherein the supply of residue for biofuel production. The basic point is that one should expect to get more and more carbon being supplied at a site the higher the price that would be paid.

3.1.5.2 Implementing carbon sequestration programs at multiple sites

An upward sloping supply curve would also be expected when implementing ACS practices across sites. Agricultural production conditions are heterogeneous across the landscape in terms of soil types, practices employed, farmer characteristics, climatic conditions, cropping systems, rotations, resource availability and access to irrigation water as well as many other factors. Such heterogeneity implies that not all sites would respond uniformly to ACS incentive payments (Antle 2001a,c).

Empirically at least six estimates have been developed. In Iowa Pautsch and Babcock (1999), Pautsch et al(1999, 2001), and Kurkalova, Kling, and Zhao (2001) showed in Iowa that some sites could deliver carbon at a zero price, others at a $200 per tonne carbon price and yet more at $400. Antle et al (2001a, c) showed for Montana wheat farms that a schedule of carbon production at prices ranging from near zero to near $400 per tonne. McCarl and Schneider (2001) show different quantities being produced on an U.S. national basis at prices between zero and $500 per tonne as do House et al(2001) and Greenhalgh and Faeth (2000). In Europe, de Cara and Jayet(1999,2000) find similar magnitudes for offsets.

3.1.6 Differences between technical and economic potential

One important distinction relevant to this discussion is the difference between technical and economic potential. There are a lot of estimates in the literature which are presented as indicative of technical potential for ACS i.e. see the review in IPCC(2000, 2001) and the evidence in Paustian et al(2001a). These estimates are usually developed using a GIS based land inventory and a multiplication by either a nationally/internationally "representative" constant or a simulation model derived rate of carbon sequestration per acre indexed to the various categories within the GIS land classification. This ignores the potential presence of the upward sloping cost relationship for exploitation within and across the GIS classified lands. Such analysis can overstate the potential substantially. For example McCarl and Schneider (2001) study sequestration potential for opportunities involving U.S. croplands and find a substantial difference between technical and economic potential for an ACS action by calibrating a model associated so that if all cropland tillage based opportunities were adopted that the lower end technical potential estimate developed by Lal et al (1998) would be achieved. In turn they went back into the model and developed the supply curve that arose when different levels of incentive payments were paid. The results are portrayed in Figure 1. There we see that the technical potential is never reached with response estimates falling far short even for the immense carbon prices in the neighborhood of $500 per tonne. The figure also shows a slow creep toward the technical potential for higher and higher GHGE offset incentive prices. In fact, as we will discuss later, even this is misleading because the economic potential estimate is developed under the unrealistic assumption that conservation tillage practices are the only thing that could be done in a greenhouse gas abatement program. Once other opportunities are considered the economic potential (see the figure 1 competitive economic potential line) is yet further reduced as will be discussed later in the manuscript in this section.

3.1.7 Dynamics, volatility and saturation and program design

When a farmer changes land use or management practices, the amount of carbon stored in the soil may either increase or decrease. This time path of soil C is a critical factor in the design of policies for soil C sequestration. For example, in the negotiations over the inclusion of sinks in the Kyoto protocol, the issue of "permanence" of sequestered carbon has been a much-debated question. The discussion heretofore has dealt with GHGE offsets from a practice as if they were constant over time and as if once soil carbon was sequestered or emissions reduced that this effect is permanent. Actually permanent retention (commonly called permanence) is not necessarily the case. Also in this regard, there are substantial differences between the permanence characteristics of carbon sequestration vis a vis emission offsets.

3.1.7.1 Carbon sequestration saturation

Once an ACS practice is put into place soil carbon begins to accumulate until it reaches a new equilibrium whereupon the absorptive capacity of the soil is used up and the soil saturates. The time it takes to reach the point of saturation is dependent on the soil, the climate and many other factors but may be largely achieved in 20-25 years. West and Post (2001) studied the carbon results of 67 long term agronomy experiments involving 276 paired treatments finding paraphrasing their abstract that carbon sequestration rates can be expected to peak within 5-10 years with soil organic carbon reaching a new equilibrium in between 10 and 15 years. Simulations using the Century ecosystem model show that most increases in soil C in response to permanent changes in land use or management practices occur in the first 20 years (Antle et al. 2001a). Lal (2000) asserts that much longer saturation times have been found in other cases. Regardless of the time frame, the point is that after an initial period one should expect a decreasing carbon increment over time from an ACS practice and that the majority of the carbon gains probably occur in the first couple of decades.

Furthermore, once stored the embodied sequestered carbon is volatile. When an ACS practice is discontinued, say reverting from reduced tillage practice back to conventional moldboard plowing, research shows that most of the carbon that was added by the ACS practice is released relatively quickly (in 1-3 years) as the system reverts back to the pre-

ACS practice equilibrium (****CITATION FOR THIS CLAIM****). This implies that if an ACS program goal is to permanently retain the GHGE offset then the program must be designed to sequester additional carbon and to cause actions that retain the carbon once the soil becomes saturated. This may entail maintenance payments beyond the time when effective saturation has been achieved. However, it is also possible that once farmers have adopted ACS practices, they may find that the practices may provide benefits (such as higher or more stable yields) sufficient to justify any additional costs.

McCarl and Murray (2001) investigate the relative value of ACS and emissions offsets taking saturation and permanence into account. They find that ACS activities are worth less per tonne than are emissions, providing that the farmer would discontinue the practice if payments cease or that payments would have to continue beyond the saturation point. One-way to deal with this issue would be to create a grading standard that would discount the amount of carbon credit for the possibility of saturation or lack of permanence. The tonne-year accounting approach discussed in the policy implementation section could also help deal with this issue.

3.1.7.2 Saturation and use of other inputs

Dynamics and saturation have important implications when the ACS practice utilizes inputs that cause GHGEs during their manufacture or application. Consider a carbon sequestration program that increases the use of nitrogen fertilizer. During the time when the practice is employed, soil carbon is sequestered but there are also additional carbon dioxide emissions from fertilizer manufacture (see discussion of this case in Schlesinger (2000) and application related nitrous oxide releases (see discussions in IPCC, 2001b). If such a practice were to be continued forever, emissions from the fertilizer manufacture and application would continue even after the soil reached a saturation point and at some future time the total carbon equivalent net emissions account would become positive. Under these circumstances, an ACS policy would be justified only if the value of ACS was higher in the present than in the future.

3.1.7.3 Permanence of avoided emissions via reduced fossil fuel use

Some critics of ACS allege that permanence is an issue only for soil carbon and not emissions avoidance in other parts of the economy. However this may not be true. For example when an emission reducing policy involves reductions in fossil fuel usage, that fossil fuel is available for future use at a lower price due to increased abundance, thus the potential emissions are still awaiting release. The form is probably less volatile, but permanence can still be questioned.

3.1.8 Comparing GHGE alterations at different points in time

The concepts of saturation, volatility permanence and dynamics introduced above imply that GHGE offset and cost calculations need to account for net GHGE reductions created over different time periods. This has been treated in the literature under the topic of discounted carbon (Richards(1997); Fearnside, Lashof, Moura-Costa(2000)). In particular, under a constant real carbon price, the net present value of a stream of GHGE reductions would involve the discounted sum of the constant real price times the GHGE increment. Equivalently, this is the carbon times the sum over time of the discount rate times the GHGE increment. Such a sum of the discounted rate times the carbon increment has been referred to as the discounted quantity of carbon and differentiates GHGE reductions in the future from current emission savings. The general concept is that future GHGE savings are not worth the same as equal offsets are today.

3.1.9 Future carbon prices

The carbon discounting approach generally ignores any dynamics in the carbon price. Full implementation of the KP is only a small first step toward stabilizing atmospheric concentrations of GHGs. Under a very conservative assumption that future technology will not make GHGE reductions substantially cheaper, an increasing real carbon equivalent price over time is likely since ever more aggressive policy will be needed if GHG atmospheric concentrations are to be stabilized. Sohngen, Mendelsohn and Sedjo(2001) also argue that as concentrations and damages build so should the cost of additional emissions (the carbon price). In either circumstance, the appropriate discount rate for GHGE may need to be negative reflecting a faster growth rate in carbon equivalent prices than in the discount rate.

3.1.10 Project versus globe – Leakage Occurs

The effectiveness of sequestration can be undermined if what is called leakage in the Kyoto context or slippage in the agricultural context occurs. Namely actions to enhance carbon (C) storage may alter current or anticipated production levels, in turn creating alterations in market conditions (e.g. price effects) that can induce an increase in emitting activities elsewhere (Barrett(1994)). This means that the gains from an onsite ACS could be offset by expanded emissions elsewhere and implies that the sequestration credit accounting system could contain leakage based reduction factors.

Leakage can manifest itself in a number of ways. Consider an example involving forest carbon sequestration. Suppose, in the name of carbon sequestration, we restrict harvest in a significant region in the Pacific Northwest. Such an action would reduce the amount of Pacific Northwest grown timber entering the market. However, overall market demand is not reduced under the project, so consumer prices would rise and consumers would look for additional wood from other sources. In turn, it is possible that the reduced Pacific Northwest harvest would be substituted for by additional harvest in other regions with accompanying increases in GHGE. In fact, this has happened, reductions in Pacific Northwest public lands harvest in the "90s have been matched by accelerated rates of harvest in Canada and the southern U.S. (See Wear and Murray (2001) and Murray, McCarl and Lee (2002) for discussion who both treat this case deriving leakage estimates in the neighborhood or 85%). Such a phenomena is a reflection of market forces

Leakage could also occur when pursuing ACS programs. For example we could convert a significant amount of cropland into grasslands in one region in the name of ACS. In turn, that conversion would lower production and raise prices stimulating producers in other regions nationally or internationally to try to meet any associated market shortage by developing croplands from grasslands, forest lands or wetlands. Wu finds in the case of the CRP that about 20% of the acres diverted were replaced by other acreage with 9 to 14% of the environmental benefits offset. Slippage findings have also appeared in the context of farm program land set asides where Hoag, Babcock, and Foster (1993) , Brooks, Aradhyula, and Johnson (1992) and Rygnestad and Fraser (1996) all found that acreage reductions were larger than total production reductions because of retirement of less productive lands in a heterogeneous landscape. Wu, Zilberman and Babcock(2001) show that such problems make cost benefit analysis of individual projects misleading and argue for more comprehensive treatment.

International effects may also occur. Felder and Rutherford (1993) show that in the energy market leakage can arise as a result of indirect price effects, as when carbon emissions reductions in one region are offset by increased emissions elsewhere, brought about by rising prices. In a modeling study and an ACS setting, Lee et al (2000, 2001) show unilateral implementation of an agriculturally based GHGE offset program in the U.S. leads to a decline in U.S. agricultural exports and an increase in production in the rest of the world, which is indicative of leakage. A number of other studies have been done in the energy industry finding leakage estimates to be 20% and below (Oliveira-Martins, Burniaux, and Martin(1992); Manne and Rutherford(1994); Jacoby et al (1997); Smith(1998); Barker(1999); Bernstein, Montgomery, and Rutherford(1999); Anderson, and McKibbin(2000); and Babiker(2001))

The KP contains discussion relevant to ACS induced GHGE reduction cost in its treatments of projects and leakage. In particular, while the KP treats participating country GHGE accounting on a comprehensive national basis, it discusses (under the Clean Development Mechanism among other places), the execution of GHGE offset projects in non-Annex I (non participating) countries which are supported by participating countries. In that discussion, the leakage concept acknowledges that the development of a project in a particular place might cause offsetting actions in other places. Such actions would offset the net global GHGE reduction causing the increment to be smaller than would be accounted when just examining the project.

Collectively the existence of leakage implies that programs need to be evaluated under a broad national and international accounting scheme so that leakage is estimated and the program achieves cost effective global GHGE reductions. Project evaluations need not only look myopically at the project but also at major competitive regions that may be affected when project activities are imposed so that net GHGE estimates can be formed.

3.1.11 Co-benefits from ACS activities

A number of ACS activities simultaneously help control erosion, alter water quality, support farm incomes, and improve agricultural productivity as shown in McCarl and Schneider(2001). Costs may also arise through increased pesticide use or diversion of resources from food production raising consumer prices. Significant proportions of these benefits fall to parties external to the farm producer who is employing them. This raises an important economic issue of inventorying and valuing benefits that accrue above and beyond net GHGE reductions as well as the economic issue of determining how the incentive system might be designed to reflect the value of these other effects. McCarl , et al (1999) looked at this issue in the context of carbon based fuel taxes and found a large offset due to benefits rising from reduced soil erosion. Plantinga and Wu(2002) examine this issue in a Wisconsin afforestation setting and find that the co-benefits arising from soil erosion and nitrogen runoff offsets are almost as large as the carbon benefits. Bondelid et al(2001)use a GIS and water quality simulator linked to a sector model to look at the incidence of a national ACS program and find incidence of substantial changes is forecasted river based water quality. Finally, we should point out that these benefits provide an argument for a public role in paying for ACS adoption to reflect the vale gained in these other benefit categories as will be discussed below

3.1.12 How are GHGE offsets affected by climate change?

An issue that has emerged in the context of the KP negotiations involves the effect of GHGE concentration driven climate change on sequestration rates. Carbon dioxide fertilization has long been found to stimulate plant growth and the amount of above ground biomass so increasing GHGE concentrations could well influence sequestration rates. Based on some analysis done for the U.S. negotiators at the COP-6 negotiations by Murray and McCarl (2000), it was argued that climate change effects would increase the amount sequestered in forest by about 10 percent. Such affects would likely increase the amount of organic matter potentially sequestered in agricultural soils as larger plants generally mean larger roots and more residues. However, simultaneously it is known that soil organic matter is reduced in warmer climates due to temperature enhancements of the rate of microbial decomposition. Thus climate change induced temperature rise could have a mixed effect on the efficacy of carbon sequestration programs.

3.1.13 Project implementation contract concerns

There are events that may arise in terms of ACS policy implementation which require contractual term consideration or policy design attention. In particular, Sampson (2002) identifies several types of risk that could accompany ACS practice adoption (largely in an afforestation setting). They are:

- Installation failure – the risk that a project will not be installed as planned as
    - the planned practices may not be well adapted to the site,
    - the installation procedure may be inappropriate, or
    - a bad year may cause installation failure.
- Maintenance failure – the risk that the ACS developer does not properly manage and maintain an installed project.
- Performance shortfalls – the risk that an installed and maintained project does not perform as predicted where monitoring and measurement reveals changes in GHGE offsets that are significantly lower due to unforeseen climate conditions, bad original estimates of GHGE offset potential, or erroneous technical information, among others.
- Abandonment – the project may be discontinued at some future date

due to landowner death, land sale, altered land use decisions or other reasons.
- Disasters – GHGE offsets may be reduced by fire, flood, weed or pest outbreaks etc.
- Practice Obsolescence – Project activities may become obsolete and ineffective due to unforeseen factors like pest resistance to herbicide methods (see Mitchell and Bennett (2000 for discussion).
- Political, Technical, Price Risks— Political decisions, changes in technology and/or price affects may compromise project offsets.

In the face of such risks a number of actions are possible

- Contracting can be designed to assign liability with incentives included for excess performance and penalties for shortfalls, as in the SO2 program in the United States where large liabilities for shortfalls are included (Stavins, 1998, 2001a,b).
- Uncertainty discounts may need to be applied. For example, Canada in the KP negotiations recommended that contracts be established based on a level of carbon one is 95% sure would arise as the level to use. However, the risk mitigation affect across portfolios needs to be considered
- Design standards can be established and a local/peer review process established to try to avoid installation problems.
- Practice monitoring and contract enforcement can be implemented to insure practices continue.
- Contract provisions could be needed that bind current and future owners such as a conservation easement.
- A reserve pool of offsets may be developed that insures against shortfall.
- Formal insurance instruments may be developed is the most common form of protection against such risks.
- Broad range of projects may need to be aggregated, including different types of projects in different geographic areas using different offset strategies to obtain diversification induced reductions in overall portfolio risk.

3.2 Mechanisms to promote ACS activities

Widespread implementation of GHGE offset strategies GHGE mitigation policy and market design involves a venture into a challenging arena because carbon is held in a non-point, geographically widely distributed fashion. The challenges with respect to policy and environmental improvement incentive design in such an arena are well illustrated by the checkered 70-year history of programs designed to control erosion where rules and approaches get redesigned on a seemingly 5 year cycle. Monitoring of program effectiveness, targeting payments to those who can make a difference in erosion based pollution and management of program administration costs have proven to be major design issues. In addition, the national and international markets into which products enter raise leakage issues, which complicate program design. Thus, a second major grouping of ACS economic issues we discuss involves the way that programs could be implemented to promote ACS.

In organizing our discussion we again address a series of questions. In this case the questions are:

- How might a program be structured and organized?
- What are their major program targeting issues that will influence the cost of GHGE reductions?
- Is there a role for including subsidies in the market framework that reflect "co benefits"?
- What lessons can be drawn from the history of other programs relative to program design?

While we treat these issues independently of the cost of carbon issues presented in section 2.1, the form of the program implementation will certainly add to the buyer and/or government costs of obtaining GHGE offsets. Any form of program implementation will involve transactions costs from market intermediaries, certifying agencies, monitoring groups etc. Those costs will affect the prices paid by carbon-offset buyers. In addition, program design includes major targeting issues that influence producer eligibility for program incentives and the extent to which the incentives will be directed toward the most efficient producers of GHGE offsets.

3.2.1 How might a program be structured and organized?

There is a fundamental issue of policy design that is arising. In particular, there are advocates for a market based approach and there are advocates for a folding of the carbon incentives approach into the farm program. Finally there is the possibility of a mixed approach that has both government program and market based aspects. Here we will try to discuss all three.

3.2.1.1 Government incentive program design

Bruce, I have a basic problem with this section (and by implication, the preceding discussion of permanence etc). The discussion follows the line that soil carbon is a commodity that will be traded like other commodities. Then one has all the problems associated with permanence etc. The other way to look at soil C is that farmers are selling a service, not a commodity – a service to accumulate and store C for a specified period of time. When viewed that way, the permanence problem is resolved, one just needs monitoring to ensure compliance with the contract. The implication of this line of reasoning is that soil C contracts may well not be traded like other emissions credits. One might even argue that, due to these features, transactions costs for truly tradable emissions credits from soil C would be prohibitively high. I think this means that soil C is more likely to be a part of government subsidy programs that emissions trading schemes. Per G.W. Bush's recent pronouncements, this seems to be the way the US is going.

We should make the point that there is a tradeoff in the choice of policy mechanisms: a marketable permit system is presumably more efficient in the allocation of effort across different sources of GHGE reductions but also has various transactions costs to deal with permanence etc., whereas government allocation across sources is less efficient in the production of GHGE reductions but has lower transactions costs.

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3.2.1.2 Private market design

Much of the trend today in environmental improvement programs and much of the discussion in the KP involves market and/or incentive based approaches. This section will deal with such approaches. In organizing our discussion we again address a series of questions. In this case the questions are:

- How might a program be structured and organized?
- What are their major program targeting issues that will influence the cost of GHGE reductions?
- Is there a role for including subsidies in the market framework that reflect "co benefits"?
- What lessons can be drawn from the history of other programs relative to program design?

3.2.1.2.1 How might the market be structured and organized?

Commodity markets have operated for a long time. A number of authors have addressed why markets have failed which conversely can be used to consider the aspects of successful market design (e.g. Gold (1975), Hieronymus(1975)). Some authors have focused on lessons learned about the structure of environmental commodity markets (e.g. Stavins(2000,2001a,b) and Kosobud(2000)). Sandor and Skees(1999) present discussion of agricultural sequestration related GHGE market establishment issues. Our reading of these sources led us to present our discussion based on a set of principles that underlie a successful market. These are that the market must have

- A commodity differentiated by grades and standards
- A scarce commodity allocated to participants having value
- Rights to buy and sell the commodity - GHGE permits and offsets
- A place to trade, exhibiting free entry and departure, observable prices
- Forms of risk management mechanisms
- Contract terms which give no advantage to buyers or sellers
- Instruments which allow a broad set of compliance alternatives
- A certifying mechanism that indicates the GHGE obligation has been fulfilled
- Implementation costs that are not excessively high
- GHGE offsets that are additional

3.2.1.2.1.1 A commodity differentiated by grades and standards

Fundamentally, market developers and scholars of market development argue that successful markets must operate over an identifiable and definable commodity, which people can trade. This does not necessarily mean that the commodity throughout the market has to be GHGE offsets or offset equivalents. Rather, there may be different types of commodities or services traded at different stages of the market. Those contracting with farmers might trade for practices (as is being done in an Iowa implementation for GEMCO - a consortium of Canadian energy companies) like adoption of manure lagoon covering, minimum tillage or retirement of land into grasslands. To implement this there would need to be a mechanism established to give GHGE offset ratings for ACS practices which allows brokers to convert practices adopted into quantity of GHGE offset equivalents. In turn, GHGE offsets would be the likely item sold to other market participants who would in turn use them to meet their emission quotas.

There is a long history of incentives to get farming practices adopted where the practices fall in the total set of ACS practices. For example, erosion control efforts implemented throughout much of the 20th century involve programs of subsidies, regulations and market incentives which have not been directed toward the quantity of erosion reduced, but rather toward the adoption of practices like retiring land in the CRP program, using conservation complying practices when participating in the farm program or installing particular practices in structural erosion measure subsidy programs. Furthermore, in the wetlands program those who wish to convert wetlands for other uses have been able to buy credits for acres of manufactured wetlands as certified under the program (Shabman, Stephenson, and Scodari(1998)).

The need for a homogeneous commodity may cause some difficulties with respect to ACS programs because of the volatility, saturation and dynamic characteristics of the practices. Specifically, factoring in the volatile, saturating nature of carbon over time would necessitate dynamic commodity ratings, complicating long-term commodity purchases and the comparison of sequestration offsets with emission offsets. As such there have been proposals arising in a number of circles. Most recently the proposal from Colombia (2000) in the KP related COP-6 negotiations, suggesting that sequestration should be rented for a given time period rather than purchased. Perhaps a grading system could differentiate among the sequestration and emission offset alternatives.

3.2.1.2.1.2 A scarce commodity allocated to participants having value

Currently there is a lot of discussion regarding GHGE markets with some firms acting as if such a market existed. However, in the US and many other places, the total quantity of emissions is not restricted. As such the value of avoided emissions to any individual firm theoretically should equal zero, although the society wide climate change externality imposed by global emissions suggests the existence of a social value and firms under a precautionary principle are exploring their options in anticipation that such a cap could arise. Necessarily in the long term there needs to be an overall emissions cap in order that GHGE offsets become a tradable commodity.

Once a total GHGE emission cap is set the GHGE permits need to be allocated to participants. Traditionally, in the environmental arena, permits have been distributed on some formula basis without charge, but it has been argued that this is inefficient as it conveys scarcity rents to the participants (Fullerton and Metcalf(2000)). Goulder, Parry, and Burtraw (1997) argue that there would be a 25 percent less Sulfur Dioxide trading if permits were auctioned rather than freely allocated. Furthermore, Stavins(1995) argues that aggregate abatement costs are sensitive to the initial permit allocation.

Finally, even if a cap is applied, then for a market to be viable with trades desirable the participants must have widely varying costs of abating emissions or generating sequestration credits (Newell and Stavins(1999)). This is likely true in the ACS case as some ACS cost estimates are as low as $0 dollars or even negative costs per tonne carbon while Weyant and Hill(1999) show a range of industrial abatement cost estimates that average from $44 - $89 per tonne carbon depending on the trading assumption with estimates occurring at levels as high as $227.

3.2.1.2.1.3 Rights to buy and sell GHGE permits and offsets

Market implementation will require the creation of an instrument, which conveys an amount of allowed GHGE between parties and accompanying legal mechanisms in the case of a shortfall by the producer or nonpayment by the buyer. Also a mechanism needs to be put in place for the generation of credits through sequestration activities. This sequestration credit case is different from trading conditions involving traditional commodities like corn or wheat as there never will be an associated physical conveyance. Rather the emission offsets will be concentrated in the soil of some field somewhere.

The instrument may also indicate the type of ACS practices that the seller is required to carry out and the quantity of GHGE offset gained. Stavins(2000) argues that the rules determining calculation of the quantity of offsets gained should be clearly defined up front, without ambiguity and that they should not have to involve trade by trade approval as that would increase uncertainty and transaction costs, discouraging trading.

3.2.1.2.1.4 A place to trade, free entry and departure, observable prices

Markets by their very nature are designed to convey commodity valuation to participants through prices, thereby stimulating a mixture of trading and price influenced decisions, which result in efficient resource usage. For market information to be efficiently exchanged and trading to occur, there needs to be a central trading location or electronic market. This could perhaps be modeled after the sulfur dioxide trading scheme on the Chicago Board trade, trading schemes facilitated by firms (see the web based The Carbon Trader(2000)) or more local schemes facilitated by state or local agencies as have occurred in trading water in California (Howitt (1994,1998)) or water quality (Woodward and Kaiser(2002)).

3.2.1.2.1.5 Emergence of supporting risk management mechanisms

Agriculture has always been a risky business in terms of the yield and cost of commodities that are produced. Agriculture will also be a risky producer of GHGE due to spatial and practice heterogeneity. Mechanisms may be needed to share this risk. These mechanisms may involve buyers, sellers or both.

On the buyer side, market structure and contract size are likely to help mitigate risk since contract size will probably involve participation by multiple producers. Thus it is likely that brokers will act as consolidators unifying contributions to GHGE offsets across many producers and possibly many GHGE reduction strategies. Consequently, brokers are likely to offer a portfolio product, which has reduced risk characteristics in comparison to a direct contract with any one individual. These are likely to integrate across different types of offset strategies like cattle based and ACS based practices diversifying the risk.

Furthermore, there may also be reason to follow a suggestion by the Canadian team in the KP negotiations where instead of a contract involving the average amount of carbon, that a risk discounted quantity could be quoted. Namely the contract would specify an amount of offset that would occur with a probabilistic level of certainty. For example, the contract could specify an amount of carbon that would occur or be exceeded 95 percent of the time. This could either be established in the set up of the trading instruments or would likely be a consequence of high enforcement costs for shortfalls.

On the seller side, as discussed above, characteristics of practices may increase risk either in the short run or the long run and forms of insurance may be needed to facilitate participation.

3.2.1.2.1.6 Contract terms give no advantage to buyers or sellers

A traditional requirement of commodity markets as mentioned by Hieronymus(1975) is that the market must be structured so that there is no advantage in information flows or competitive position for either buyers or sellers. This is unlikely to happen on the seller side regarding ACS practices as there are a large number of potential actors. Many actors are also present on the buyer side since it includes power plants, energy companies and other industrial enterprises. Establishment of an electronic, or physical marketplace would also facilitate information flows.

The number of brokers in any given area under the broad geographical characteristics of agriculture, which could lend spatially based, imperfect competition dimensions to the market. Also government license or emission certifying requirements and costs might restrict the number of entrants into the market

3.2.1.2.1.7 Instruments which allow broad set of compliance alternatives

One requirement Stavins(2000) prominently mentions for environmental attribute trading markets is that the market must be able to accommodate a broad set of compliance alternatives. This implies that a market focused just on carbon sequestration will not arise but rather one focused on a broad set of GHGE emission offsets. Such a market would include emission permits or offsets generated by a wide variety of firms including firms reducing emissions by lowering fossil fuel use as well as firms that use ACS practices and agricultural firms that would reduce emissions by altering fertilization, and manure management or rice acreage among other opportunities.

3.2.1.2.1.8 Certifying that the GHGE obligation is fulfilled

A common discussion regarding carbon sequestration involves concerns about monitoring, verification and enforcement. Concerns over these issues have led some to doubt in whether carbon sequestration based ACS programs can be effectively implemented without very large transactions costs. Stavins (2000) points out that experience with market-based instruments in numerous environmental settings show programs can fail if monitoring and/or enforcement are deficient. Certainly the additional costs of measuring and monitoring carbon credits produced by any project imposed by contract provisions needs to be considered as part of the cost of producing GHGE offsets (as argued more generally in Moxey, White and Ozanne 1999).

Post et al(1998) review literature on monitoring and verification showing that the cost of these activities depends critically upon the accuracy desired. Kaiser (2000) reports "...a pilot project in Saskatchewan has convinced some experts that a statistical approach can bring down the costs of measuring carbon uptake. The 3-year project, supported by energy utilities interested in buying carbon credits from farmers, combined statistical sampling with modeling on 150 farms. It concluded that carbon absorbed by changes in land use could be measured for a relatively low 10 to 15 cents per hectare, according to Brian McConkey of AAFC". Lal et al (1998) presents a similar estimate. Mooney et al (2002) estimate the cost for a single field sample is estimated at \$16.37 and indicate the figure is similar in magnitude to the experience of Smith (2002) who reports costs per sample of approximately \$25 for a project in eastern Oregon.

Efforts have also been directed toward the use of computer simulation models to derive carbon ratings by soil supplemental to field based sampling as an input to cost effective targeting mechanisms (see Antle et al (2000, 2001a, b, c), Paustian et al (2001a, b), Mooney at al(2002)). A key economic issue that arises in regard to these concerns involves the trade-off between the value of more precise information and enhanced program efficiency, versus the transactions costs of the monitoring and verification operation. This is a variant of a well-known economic problem involving value of information and sampling design.

Guidelines have been developed for measuring and monitoring carbon within forestry and agroforestry projects (MacDicken, 1997; Vine, Sathaye and Makundi 1999; Brown 1999). However these guidelines concentrate on above ground carbon stored in trees not in the soils. A number of scientific methodologies have arisen to measure carbon and there is still a quest for rapid low-cost means Post et al (1998), IPCC(2000), Paustian et al(2001a, b)). Also substantial efforts are being devoted to simulating carbon quantities (Parton et al (1987, 1994), Paustian et al (1992, 1996, 2001a, b), Izaurralde et al(2001)) and observing carbon increments through remote sensing.

The measurement frequency will be influenced by the duration of the project and the rate of carbon accumulation (Mooney et al, 2001). Measurements on continuing projects may not need to be conducted annually because carbon levels do not change dramatically. Vine and Sathaye (1997) and Vine, Sathaye and Makundi (1999) suggest a five-year interval for forest projects provided no disturbance has taken place. McConkey and Lindwall (1999) suggest a three-year interval on fields converted to no-till. Brown et al. (2000) plan to measure carbon in a 30-year forest project in years 3, 5, 10, 15, 20, 25 and 30. At a minimum Mooney et al (2001) assert one needs to establish baseline levels of carbon at the beginning of the project and final carbon levels at its conclusion.

On the enforcement side some form of liability needs to be introduced to cover cases when the quantity of emission offsets sold are not actually achieved and where the buyer fails to pay for the emissions offsets according to the contract terms. In the sulfur dioxide case the authorizing legislation introduced penalties, which were much greater than marginal cost of generating emission offsets. Stavins (1998) argues that magnitude of penalties has been an important determinant of the high degree of compliance and the emission management program success.

3.2.1.2.1.9 Implementation costs must not be excessively high

The assembly of a group of farmers to sell carbon offsets to a emitting entity will require implementation and accompanying transactions costs as would monitoring and certification of the quantity of carbon produced. Transaction costs have been identified as one of the greatest hurdles for tradable permit systems (Hahn and Hester 1989) and their magnitude will have important consequences not only the size and efficiency of markets, but for their overall structure. Atkinson and Tietenberg, (1991) review cases where the transactions costs caused market participation to be substantially lower that was expected. McCann and Easter(1999,2000) argue inclusion of transactions costs is an important aspect of the problem that is frequently omitted. Stavins (1995) shows this biases the comparative desirability).

Agricultural programs have traditionally exhibited substantial transactions costs. Alston and Hurd (1990) estimate that the transactions costs of administering the farm program ranged from 25 to 50 cents for each dollar distributed. McCann and Easter(2000) find transactions costs of the magnitude of 38% of total costs or over 50% of direct payments. Often it is argued that private based incentive programs can help hold down these costs. Obviously substantial attention needs to be paid in program design and operation to ensure that transactions costs do not become excessive.

3.2.1.2.1.10 GHGE offset producers, the baseline and what is additional?

Before a GHGE market can be created, appropriate eligibility standards for the producers and who remain already have adopted ACS practices along with a baseline level of emissions must be set. The definition of such standards and a baseline raises a number of issues.

In particular, in terms of eligibility, if some land was in the process if being switched to no till agriculture before the program begins then should any level of carbon payments accrue to that land under the program? More over would existing forests and existing reduced tillage farms be entitled to receive credits for carbon already sequestered or nutrients flows already reduced? Would they be able to receive credits for following a management strategy that was already in place when the market was created?

Baselines and additionality have been key concepts arising from the Kyoto negotiations. In particular much of the discussion surrounding the protocol involves the fact that GHGE offset quantities should only count against a country's total when they are truly additional to what would have happened in the absence of an emissions cap. The argument is that countries should not be able to claim GHGE offset credits that would have arisen anyhow under business as usual operations but rather should only get GHGE credits when an active decision is made to generate them. To implement this a baseline is needed which is forward-looking having the future path of GHGE, which would have arisen in the absence of any moves to reduce emissions. This suggests that the baseline n foresee for example future movement of land into forests stimulated by increased forest products demand and a credits system, which would not generate emission credits for any such movements that would have been carrying out under business as usual. This raises many practical problems including how one would construct such a baseline and then how one would go down to explaining eligibility to private landowners on land that "would have converted anyway". The establishment of the baseline and the eligibility standards is a policy decision with enormous distributional impacts that will affect the overall efficiency of any market-trading program.

3.2.1.2.1.11Intermediaries in the market

Participants in a GHGE emission market probably will include more than just offset producers and buyers encompassing a set of intermediaries or brokers to facilitate market operation particularly in the ACS practice arena. It is widely expected that a large number of AF sellers will seek to sell a few credits, while a small number of buyers will seek to purchase large quantities. For example, today the contracts discussed involve 100,000 tonnes. Brokers or some other type of intermediaries will be needed to reach such a size consolidating the commitments on behalf of a number of offset producers. In turn those intermediaries would sell the resultant consolidated commitment to buyers or consolidators who had assembled groups of buyers. Today such a program is operating in Iowa where an insurance company is buying practices from groups of farmers and then dealing with an entity representing a consortium of Canadian energy companies who are buying offset contracts.

Intermediaries will introduce a wedge between buyers and sellers composed of the transactions costs of their activities. The use of brokers may be the only way to effectively consolidate ACS supplies in many instances. For example, suppose we consider two ways of assembling a continuing 100,000 tonne per year offset contract using ACS practices and we use the average sequestration rate found the array of tillage experiments examined by West and Post(2001) of 0.57 tonnes per hectare or 0.23 tonnes per acre:

- if a country were to pursue a project under the KP "Clean Development Mechanism" in a developing country with a relatively small farm size or 2 ha per farm, then a 100,000 tonne contract would require assembly of commitments from about 220,000 farmers.
- If a contract were established in the Midwest United States where farm sizes are some land on the order of 200 hectares per farm and we got the same sequestration rate somewhere on the order of 2200 farmers would need to commit to the program.

Either way the assembly of these groups would be a daunting task to manage and could lead to high transaction costs. Furthermore, the resulting magnitude of transactions costs may also act to exclude some groups (e.g., smaller farms or forests) from the market as the costs are likely to involve a fixed cost per participant and a variable cost component that grow with participant size. Larger fixed cost components could well exclude smaller participants. Alternatively, government or government-authorized clearinghouses might be created that reduce the private costs of making the link between buyers and sellers. The role and costs of intermediaries need to be given explicit consideration in a market's design.

Brokers also could also serve to reduce buyer risk by consolidating a portfolio of different offset and emission production possibilities creating a mutual fund type product, which would likely have lesser risk than any component of the portfolio.

3.2.1.3 Mixed market design

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3.2.2 Common concerns across market forms

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3.2.2.1 Targeting influences the cost of GHGE reductions

Targeting refers to the manner in which the rules under which a GHGE program is established direct payments to offset producers. Targeting cost concerns involve the resultant cost per unit of GHGE reductions. From a strictly economic standpoint the goal of targeting is to direct payments to those who would produce the greatest quantity of GHGE offsets at a given price. Targeting accuracy is an important determinant of overall program costs and success. ACS practices have proven to be difficult to target. Historically a lot of money was spent on erosion control practices, which did not greatly reduce erosion but certainly cost money (Nielson(1986)).

Targeting issues have been behind many of the revisions in U.S. erosion control programs as well as many of other environmental improvement programs. There are major targeting issues and consequences regarding the ACS activities that revolve the basis for targeting, the possible exclusion of those already using the targeted ACS practices and exclusionary actions and property rights

3.2.2.2 Basis for Targeting

The basis for targeting is an important issue involving whether one targets at actual GHGE offset quantity or adoption of practices and introduces a substantial tradeoff between ease of program implementation and targeting cost effectiveness.

3.2.2.3 Carbon Potential versus enrolled acres

The literature on design of environmental policies for agriculture has noted that, ignoring contracting costs and market imperfections, existing policies are inefficient in the sense that they pay farmers for the adoption of alternative practices rather than per unit of environmental benefit provided by the practices, and thus do not account for the spatial variability in benefits and costs associated with the adoption of improved management practices (see Babcock et al., 1996; Helfand and House, 1995; Fleming and Adams, 1997). Efficient incentive mechanisms would account for the spatial heterogeneity in the environmental benefits produced and the costs of providing these benefits.

The basis for targeting whether payment eligibility is determined by acres in a region or carbon potential can influence the cost of carbon generated. McCarl(1998) shows that targeting in an ACS setting involving an afforestation case can lead to very different cost per tonne implications when done on a land entered into a forest basis as opposed to a quantity of carbon produced basis with an efficient seats arising when targeting on practices the opposed to carbon. Antle et al. (2001b) show that an ACS tillage alteration program targeted to participating acres without paying attention to carbon potential could cost twice as much per tonne as opposed to a program targeted based on carbon potential (without consideration of the transactions costs of the targeting).

3.2.2.4 Costs of carbon potential targeting

Improved targeting based on GHGE offset potential can involve substantial costs. GHGE offset based targeting would require parcel specific information on the potential to produce emission offsets and accompanying cost estimates. This is complicated by the fact that emissions offsets are not constant over time so that estimates are not a once and for all number applying to all soils of a type but rather would need to take into account the soil carbon stock at the time of ACS practice implementation as well as the time path of carbon sequestration and accompanying GHGE offset production. Such difficulties motivate much of work regarding the use of computer simulation models for developing carbon ratings. However rapid practice cost estimation procedures have not been addressed.

3.2.2.5 Reasons for practice not tonne offset targeting

Soil conservation programs today such as the CRP program remain targeted toward practices. Namely the CRP program offers land retirement incentives based on acres retired, not on the impact of that retirement. However, the cost paid to participants in the program is set up based on county land rental rates and the eligibility requirements are more environmentally oriented. But a late 1990's attempt to revise the program to be even more environmental was not fully carried out as it would have dramatically altered the geographic incidence of payments.

Explanations for the continued use of per acre or per practice policies instead of per tonne sequestered or of erosion saved in the face of their economic inefficiency include the list manufactured by Wu and Boggess(1999):

- the transactions cost it would require to develop the information for and carry out site-specific policies;
- information asymmetries between government agencies and farm decision makers;
- political considerations

along with the possibility that the

- Underling differing program motivation where the programs are really income support but are implemented in the name of conservation or environmental protection

ACS practices may involve similar characteristics. In an analysis of C sequestration in forests, Stavins (1999) suggests that a payment mechanism based on tonnes of C sequestered would be prohibitively expensive to implement.

However, Pautsch et al. (2001) argue that it is useful to investigate efficient sequestration mechanisms because they provide a lower bound on costs.

3.2.2.6 Possible exclusion of those already using ACS practices

A second major targeting issue involves payments to producers already using ACS practices in current operations versus people have not been using such practices. A number of producers have already adopted ACS enhancing practices without an ACS program in place, rather acting in their own self-interest. A question for program design is will the program pay existing users of practices that were adopted sometime on before the program initiation date. Including such existing users will cause the program to be more expensive with the preexisting practice users being able sell credits even if they never intended to change practices. Excluding such producers gives incentives to for them to abandon practices creating emissions and then asking to be admitted to the program. For example Brooks, Aradhyula, and Johnson (1992) found that farm program provisions gave incentives to producers to bring lands into production that were of low quality and in turn enter them into set aside programs. A solution in the case of a government program would be to provide payments to those who could document that they had changed practices previously and sequestered soil carbon. In the case of a carbon market driven by an international agreement requiring additionality and GHGE reductions from a fixed baseline, credit for prior actions might not be acceptable. In that case, governments could prevent the perverse incentive problem by purchasing and holding credits from those farmers who had already adopted soil carbon increasing practices but not claiming those credits in the international setting. It is public policy decision whether the taxpaying public should reward such individuals for voluntary private acts that yield social benefits.

3.2.2.7 Exclusionary actions and property rights

If rules are set up to levy fees against or prevent ACS practice abandonment, those rules would certainly infringe on private property rights of individuals to manage their land as they see fit (Marland, McCarl and Schneider (1998, 2001) and McCarl and Schneider(2000b)). For example if we begin to give credits for afforestation and penalize those who later deforest their land will we penalize those who deforest who never were paid to afforest. If so we are altering the nature of traditional land management rights. This could lead to legal issues in program implementation and management as well as associated transactions costs.

3.2.3 Could subsidies reflect "co benefits"?

Agricultural policy commonly pursues multiple goals and uses multiple instruments. Income enhancement, price support, environmental improvement are just a few of the goals while loan rates, direct payments, conservation compliance requirements, and CRP land retirements are just a few of the instruments. The commonality of ACS practices with a number of the previously used instruments coupled with the existence of desirable indirect effects when using ACS practices also leads to a policy issue. Namely given the existence of co-benefits is it desirable to "sweeten" the market using public or donor money, which reflects the general, externality related, welfare gain that would arise outside a carbon market caused by the adoption of ACS practices. A number of the co-benefits of ACS practice adoption are clearly external to a GHGE market and would cause market failures in the sense argued under the topic of economic externalities (Baumol and Oates(1975)). An emission market would not reflect the value of any gains in related environmental externality accounts. These can be large, for example in an examination of an afforestation case in Wisconsin Plantinga and Wu(2002) show cases where the value of the co-benefits in erosion control and reduced nitrogen runoff are as large as the value of the carbon gains. Mechanisms might be developed to reflect these co-benefits and stimulate appropriate levels of investment along the lines of cost sharing arrangements or government/donor subsidization of market transactions costs by providing monitoring or assembly services. This might be particularly the case in developing countries where soil fertility gains or increases in food production capability through ACS programs might create a willingness on behalf of governments or donors to sweeten the market.

3.2.4 Historical program experience and program design

The above section has overviewed a number of considerations that might be pursued in implementing ACS programs. In addition we would like to note that the general concept of an ACS program has similarities to a number of programs that have been implemented in the past. We believe there are reasons to review the history of these programs to help ACS program designers in avoiding mistakes and capturing opportunities. In particular we think there are several other types of programs and endeavors that are particularly relevant

- Water quality trading programs which are beginning to emerge. Ribaudo, Horan, and Smith (1999) and Woodward and Kaiser(2002) provide reviews.
- Wetlands protection programs where projects are developed in different locations and sold to those displacing wetlands. Shabman, Stephenson, and Scodari (1998); Crosson and Frederick(1999), Scodari and Brumbaugh(1996); and Scodari, Shabman and White(1995) provide reviews.
- Soil conservation programs including conservation reserve and conservation compliance programs where practices very close to a number of ACS practices have been implemented for over 60 years in various forms. Crosson(1986); Claassen et al(2001); Nielson(1986); Magleby et al (1995).; and Hrubovcak, Vasavada, and Aldy(2000) contain reviews.
- Water Markets where surface water trades on a seasonal or permanent basis. Howitt 1994 and Easter, Rosegrant, and Dinar(1998) treat this set of markets

- Oil and mineral leasing markets where oil companies enter into agreements with land owners to drill under their lands. Such markets may have seller assembly procedures and a history of cost containment procedures that would illuminate the transactions costs of assembling groups of producers to sell GHGE offsets.
- Farmer marketing coops where groups of farmers associate to market commodities.
- Markets for air pollution rights such as California's Reclaim program and the sulfur dioxide program (Hall and Walton 1996, Stavins (2000));
- Emerging carbon trading markets in Europe and in international firms like British Petroleum
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In addition the more general reviews as in Stavins (2000) and the materials on the Tietenberg (2001) web site are instructive.

3.3 Comparing ACS strategies with other strategies

The third major question discussed here involves the comparative desirability of pursuing ACS activities. Here we address the questions:

- What is the difference between economic and competitive economic potential?
- What other GHGE offset opportunities might be pursued?
- How might ACS strategies interact with other strategies?
- How could ACS strategies cause leakages?
- How comprehensive should GHG accounting be when considering ACS strategies?
- How might we factor co benefits into an analysis of ACS practice desirability?
- How can we compare ACS offsets with emission offsets?
- How might we assess the comparative desirability of ACS?
- What is the difference between economic potential and competitive economic potential?

3.3.1 What other GHGE offset opportunities might be pursued?

There are a number of opportunities to pursue GHGE offsets above and beyond the employment of ACS practices. These include pursuit of GHGE offsets in the agricultural sector broadly defined to include forests, as well as those arising in the non-agricultural sector and opportunities through international emissions trading.

3.3.1.1 Agricultural GHGE offsets that do not involve ACS

Following the arguments in McCarl and Schneider (1999, 2000a), there are at least three ways agriculture may participate in GHGE offset enhancement efforts.

- Agriculture may reduce GHG emissions generated during operations.
- Agriculture may enhance absorption of GHGE by creating or expanding sinks which includes ACS activities.
- Agriculture may provide products, which substitute for GHGE intensive products displacing emissions.

The first and third of these and the forestry aspects of the second are the principal agricultural opportunities we discuss here.

3.3.1.1.1 Emission reductions

In terms of emission reductions, the IPCC (1996) document estimates that globally agriculture emits about 50% of all methane emissions, 70% of all nitrous oxide, and 20% of all carbon dioxide. Sources of methane emissions include rice, ruminants and manure and can be reduced by altering items such as crop mix, livestock herd size, livestock feeding and rearing practices and manure management. Nitrous oxide emissions come from manure, legumes, and fertilizer use and can be reduced by altering items such as livestock herd size, crop mixes and fertilization practices. Carbon dioxide emissions arise from fossil fuel usage, soil tillage, deforestation, biomass burning, and land degradation and can be reduced by altering items such as production fuel use, allocation of land between crops, pasture, grass lands and forests, forest harvest rates, crop residue management, forest harvest management, and land restoration. McCarl and Schneider (1999, 2000a) present a further discussion of and a review of the types of activities that can be pursued as do the EPA documents on Methane and Gas Emission Inventories (2000). On the forest side management practices that offset emissions according to Brown(1999) and Brown et al(1996) include reduced deforestation or logging, protection of forests in reserves, and reduced disturbances by managing forest losses through fire and pest outbreaks.

The relative magnitude of these emission sources varies substantially across countries, with the greatest differences between developing and developed countries. Deforestation and land degradation mainly occurs in developing countries. Developed country agriculture generality uses more energy, intensive tillage systems, and fertilizer, resulting in carbon dioxide fossil-fuel based emissions, carbon emissions from more intensive tillage, nitrous oxide emissions from fertilizer and nitrous oxide plus methane emissions from animal herds and resultant manure. Sink Enhancements

3.3.1.1.1.1 Forestry Options

Forest management practices that increase carbon retention can be classified into several groups:

- Management to retain carbon in forests including longer rotations, reduced deforestation or logging, protection of forests in reserves, reduced impact logging, and reduced disturbances by managing forest losses through fire and pest outbreaks (Brown (1999), Murray (2000) and Brown et al(1996) elaborate).
- Management for increased carbon in standing forest biomass or forest

  soils through use of enhanced silvicultural treatments, natural or artificial regeneration in secondary forests and other degraded forests whose biomass and soil carbon densities are less than their maximum value (Brown (1999), and Brown et al(1996) elaborate)
- Altered management and use of harvested wood products shifting demand into longer lasting wood products, and extending the lifetime of wood products through disposal, recycling and other preservation efforts (Brown (1999), Brown et al(1996) and Skog and Nicholson (2000) elaborate).
- Afforestation of non-forested agricultural or other lands, and increased tree cover on agricultural or pasture lands through agroforestry.

In the KP context only the last management alternative is definitively included as the language allows credits for emission sinks through afforestation and reforestation (note negotiations have defined reforestation in terms of land moving into forestry and from agriculture that was in the past forested, excluding reestablishment of trees on existing forest lands).

3.3.1.1.2 Substitute Products

Agricultural products may be grown which replace fossil fuel intensive products. One such product category involves biomass for energy generation or transformation into liquid fuels. Burning biomass reduces net CO2 emissions because the photosynthetic process of biomass growth removes about 95 percent of CO2 emitted when burning the biomass. Fossil fuel use, on the other hand, releases 100 percent of the contained CO2. Liquid fuel transformation generates smaller offsets but is still an emission saver. Also forestry products can be used to substitute for fossil fuel intensive use of steel and concrete in construction. (Marland and Schmalinger(1997), Brown (1999) and Brown et al(1996) elaborate). Finally there may be gains from substituting cotton and other fibers for petroleum based synthetics.

3.3.1.2 Non agricultural GHGE offsets

There are many opportunities in the non-agricultural sector to produce GHGE offsets. These include diverse sequestration mechanisms such as capturing GHGE from power plants and injecting them into the earth or ocean, fertilizing the ocean to increase carbon sequestration, separating carbon from hydrocarbon fuel sources before burning and then sequestering this carbon. There are also numerous emission reduction alternatives such as switching fuels, adopting energy-saving technology, and altering transportation systems. Given the agricultural orientation of this document, we only refer the reader to IPCC documents such as Jepma, et al(1996) and IPCC(2001) greatly elaborate.

3.3.1.3 International Trading Opportunities

GHGE offsets are not only relevant within a country, there may be opportunities to more cheaply develop offsets internationally. The KP establishes the principle of international emissions trading. Article 6 discusses Joint Implementation, whereby a country can pursue offset projects in other Annex I countries. Article 12 discusses the Clean Development Mechanism (CDM), under which projects can be sponsored in non-Annex I hosts. Article 17 discusses trading of emissions credits between Annex I countries. Trades between parties to the KP such as those under Article 6 or Article 17 would not create additional global GHGE permits with transfers to the buying country being subtracted from the seller. Transfer of emissions credits under CDM would create additional global emissions permits since a country with emissions restrictions would obtain additional emissions permits from a country without such. This means that ACS, other agricultural offsets or non-agricultural offsets could be obtained internationally and would thus compete with domestic ACS activities.

3.3.2 How might ACS strategies interact with other strategies?

The agricultural sector is tightly integrated due to its dependence on the common land, water and other resource base as well as the linkage created by commodity markets and the use of intermediate products. Each of these forces contributes to competitive and synergistic interrelationships between the alternative strategies.

3.3.2.1 Common Resource Base

All agricultural activities share common spatially distributed land, water and other resources. The common land base across production systems for commodities means that the amount of land moved into an alternative use influences the economics of ACS strategies, which transform land into other uses. For example, there is obvious and direct competition for land between land uses for cropland, grasslands, forests or biofuels. In general, any strategies, which change land use, alter the crop mix occupying the land, or reduce yields increasing the amount needed to grow a given volume of crop will be competitive. In such cases, the relative cost of pursuing any one strategy will depend on the amount of the other strategies employed.

In addition, agriculture employs substantial amounts of often-scare irrigation water, which can create competitive relationships.

3.3.2.2 Intermediate product relationships

The fact that many agricultural commodities are used as intermediate products in the production of other products (particularly crops as livestock feed) also influences interrelationships between strategies. For example, strategies that result in decreases in the amount of the feed grains produced increase livestock feeding costs and make it easier to pursue strategies, which reduce the aggregate size of livestock herd.

3.3.2.3 Overarching commodity markets

The common national and international commodity markets for agricultural products will cause a mixture of competitive and synergistic interrelationships between strategies. For example, the use of strategies which divert substantial cropland are likely to cause an increase in crop prices, and in turn an increase in the minimum incentive level incentives needed to employ strategies which lower yields or raise costs.

On the synergistic side, the widespread employment of a strategy that diverts substantial cropland into grasslands might make forage cheaper making it easier to alter diets for the management of methane emissions for enteric fermentation via forage substitution for grain.

Finally, there are implications transmitted through the final and intermediate product commodity markets across the widespread geographic dispersion of agriculture. Production system alterations in one region may influence prices and cause production alterations in other regions and even across countries through domestic and international trade linkages. Leakage may result as discussed next.

3.3.3 How could ACS strategies cause leakages?

An important consideration involves leakages or offsets. Leakage involves a reaction induced by the adoption of an ACS practice, which potentially increases GHGEs from other sources. Leakages may not only be positive but can also be negative. For example, certain types of ACS practice adoption can lead to a direct reduction in fossil fuel use or can cause other emissions reductions through product or input substitution. More generally, ACS strategies can cause leakages through

- byproduct increases in emissions of other GHGs,
- domestic and international market realignments,
- product placements.

In terms of byproduct increases in GHGEs, ACS strategies can lead to increases in nitrous oxide and carbon dioxide emissions if they stimulate increased fertilization and legume use as discussed above. Negative levels can also be encountered with reductions in fossil fuel use under reduced tillage. Offsets may also occur in methane due to crop mix or grassland conversions although the magnitude of that effect is not well known.

In terms of domestic and international market realignment, market price signals can cause production changes in other regions and offsets due to additional acreage being farmed or more intensive heavier emitting practices being used. For example Lee et al(2000, 2001) finds that under a substantial participation in GHGE offset programs in the U.S. or Annex I counties that there is the tendency to expand production in non annex I countries in the absence of full CDM implementation. Leakage is market-driven and economic in origin and thus requires an economic model or argument to examine its causes and develop nominal leakage discounts. McCarl, Murray and Lee (2002) investigate the problem economically and develop a formula showing the way market characteristics determine the magnitude of leakage and some common discount factors. They also examine an actual case and develop some estimates using sector modeling.

In terms of product and input substitution, leakage can occur when ACS strategies stimulate production of products, which in the marketplace substitute more intensive commodities that embody greater quantities of GHGE in their manufacture. For example, if an ACS strategy led to production of less cotton then synthetic, petroleum based fabrics might replace it potentially causing higher emissions. Similar types of replacements could occur in ACS strategies reduced the amount of corn going into ethanol or the amount of biofuels being produced by agriculture or forestry, or the amount of land in the forest sector causing replacement of wood products with more fossil fuel and GHGE intensive building products. There also is a substantial opportunity for GHGE alterations due to changes in transportation or manufacturing and processing requirements for agricultural inputs and outputs.

The leakage implications call for a total accounting approach in the appraisal of compared desirability as discussed next.

3.3.4 Comprehensive GHGE accounting

The leakage and strategy interaction issues discussed above imply that GHGE accounting should be as comprehensive as possible. There should be coverage of the three major greenhouse gases affecting agriculture -- carbon dioxide, nitrous oxide and methane. Accounting should consider not only the carbon sequestered, but also the amount of GHGE from fossil fuel use in input manufacture, input transport, crop and livestock production, and commodity transport. Market-based phenomenon such as the GHGE implications of supply shifts in other regions and countries should be considered as well as possibly the effects of changes in production of agricultural commodities and the resultant GHGE emissions created by substitute commodities.

Multi gas accounting in an economic framework requires one employ the global warming potential (GWP). The GWP concept (IPCC, 1996) indicates the relative heat trapping efficiency of alternative GHGs. GWP usage permits analysis of trade-offs between alternative GHGs. For example the 100-year GWP of carbon dioxide is one, methane 21 and nitrous oxide 310 indicating that an offset of one tonne of nitrous oxide is equivalent to offsetting 310 tonnes of carbon dioxide.

The reader should note that alternative sets of global warming potential numbers are available. There are traditional GWP measures based on the capability of atmospheric concentrations of a GHG to trap heat over a particular duration as in the IPCC 1996, and more recent refinements such as those in Jain et al (2000). There are also emerging estimates based on economic measures of damages imposed by greenhouse gases (Reilly and Richards (1993), Reilly, Babicker and Mayer(2001), Bradford and Keller(2000)) or the cost of achieving atmospheric concentration targets Manne and Richels(2001).

Another important consideration when doing total greenhouse gas accounting involves boundary conditions. In particular when computing the GHGE offset generated by an ACS practice which reduces fuel and nitrogen fertilizer use one would calculate the savings in the carbon emissions arising from the reduced nitrogen fertilizer use produced in the petrochemical sector and the savings in the emissions from reduced petroleum based fuel production and consumption. However it is important to keep these accounts separate as when an agricultural study is meshed with a study set within the total economy it is important to avoid double counting which could happen with respect to the petrochemical and petroleum refining sectors. However it is important when doing an agriculture sector only appraisal to a fully account for all the offsets generated by ACS practice adoption. Such accounting also needs to insure that the petrochemical and petroleum based fuel prices have not been upwardly adjusted to reflect GHGE emission content.

3.3.5 How might we compare ACS offsets with emission offsets?

The comparison of ACS alternatives with emission reductions raises the issue of how permanence, and volatility of carbon retained by ACS activities can be compared against the volume of GHGE offsets gained through emission offsets.

Suppose we consider a simplified example contrasting a hypothetical sink versus a hypothetical emissions offset. Suppose we can provide an incentive to get a producer to employ an ACS practice which offsets one unit of admissions for each of the next fifteen years but that after that fifteen years the soil becomes saturated absorbing no more. However, to retain that carbon in the soil, the practice and associated incentive must be continued for the indefinite future. Otherwise, suppose the producer will revert to the traditional practice with the sequestered carbon quickly volatizing. On the other hand, suppose we could install a piece of energy conserving equipment with a fifteen-year economic life that causes reduced emissions offsetting one unit of carbon over each of the next fifteen years. Both of these actions offset an equal quantity of carbon but the emission alternative offsets just the stock of atmospheric carbon but does not create a stock anywhere of potential carbon emissions (assuming we do not worry about hydrocarbons left in the ground) while the sequestration offsets atmospheric stock but creates a soil stock which can be volatized into the atmosphere if the practice is reversed.

Clearly there would be a difference in the economic willingness to pay between these two alternatives if the buyer needed to maintain the offset emissions beyond the fifteen-year period. Such retention is automatically the case under the emission offset, but is not under the sequestration offset. A full accounting of cost over say two decades would have to include the costs of maintaining the stock of carbon sequestered but would not need to do such under the emission offset activity. McCarl and Murray examine this and show agricultural sequestration can be worth only one third as much as a sequestration offset.

This situation is somewhat complicated for emission offsets achieved through conservation of fossil fuels as those fuels would remain a source of potential emissions in the future. Similarly GHGE capture and storage alternatives would need to reflect the maintenance costs at the storage site to avoid leakage.

All in all in appears likely that buyers would be willing to pay less for an equal volume of sequestration offsets in comparison to the same volume of emission offsets as has been discussed in a number of circles regarding the KP negotiations. How might we factor co benefits into the situation?

ACS programs can generate co-benefits as can the emission-offset strategies that could be employed. Co-costs are also possible, thus both positive and negative levels of co benefits should be considered. There are three main efforts that must be pursued regarding the inclusion of co benefits. These involve the definition of appropriate categories for the co-benefits, the quantitative measurement of co-benefits magnitudes and the economic valuation of co-benefits for use in formulating policy and subsidy levels.

3.3.5.1 Relevant co-benefit categories

There are many co-benefit categories, which can be relevant. These include a diverse blend of on and off-site alterations in environmental attributes including changes in soil erosion, sedimentation reaching waterways, dust in the air, pesticide runoff, surface water quality, wildlife habitat improvement, groundwater water quality, groundwater recharge, leaching of chemicals into aquifers, required irrigation water, long run soil fertility, and reclamation of degraded lands. There are also a number of more aggregate economy wide measures such as rural producer income, agricultural employment, consumer food cost, agricultural trade balance, and country food self-sufficiency.

3.3.5.2 Measurement of Co-benefits

Co-benefits estimates are needed for both the environmental and economic classes of co-benefits. The methods for estimating these things differ substantially between the two classes so will be discussed separately.

3.3.5.2.1 Environmental co-benefits

In terms of measurement of environmental co-benefits, three types of efforts are needed.

- Site and practice level co-benefit estimation
- Aggregate level estimation of practice employment by site
- Routing analysis of more aggregate watershed implications
-

3.3.5.2.1.1 Site and practice level co-benefit estimation

The site and practice level co-benefit estimation involves the construction of estimates of changes in physical quantities of relevant co-benefit indicators on sites where practices are to be installed or in other locations where installation of the practices causes alterations in land use managed through market forces. Such estimates would indicate changes in the fate and transport of chemicals used, erosion rates and soil water balance over time after a practice has been adopted.

Commonly the physical per acre quantities of such off site chemical effects is estimated using with biophysical simulation models such as EPIC (Williams et al(1989)) or Century (Parton et al (1987, 1994)). Field measurements can also be used but are usually geographically limited so are perhaps best used in combination with the simulators to spot verify the simulation output. Plantinga and Wu (2002) show a rather involved appraisal based on such models.

3.3.5.2.1.2 Aggregate level estimation of practice employment by site

The aggregate level estimation of practice implementation by site and involves an examination of the market and GHGE program incentive induced alterations in practices adopted across the landscape. The region of focus should include both target land areas where ACS practices are to be employed and off-site areas where leakage implications may arise. This broad-based aggregate estimation allows one to factor and the direct project effects and market-induced effects. It such an aggregate appraisal offset often uncovers unintended implications of programs. For example, in the appraisal of recent provisions under proposed farm program revision legislation Atwood, Gillig and McCarl(2002) found that conservation subsidies for reducing per acre usage of fertilizer inputs actually could increase total fertilizer usage. Namely in an aggregate sense the incentives were found to tilt the balance toward commodities with reduced per acre fertilizer use compared to pre-incentive levels but with expanded acreage substituting for crops which did not use as much nitrogen (i.e. simplistically more corn – less soybeans and more employed nitrogen on the expanded corn acreage). Similarly a Texas irrigation water conservation programs was found to be water use increasing. Namely the gains from reductions in per acre water use were more than offset by the water use stimulated by an expansion in irrigated acres stimulated by a reduction in the cost of irrigating.

This type of analysis is commonly done using some form of sector or regional model which also considers market phenomena depicting both land and practice adoption across a spatially disaggregated landscape. Examples in a co-benefit setting include the analysis in a) Atwood et al (2000) where the co-benefit effects of technology adoption were modeled based on sector model results; b) the work in Bondelid et al(2001) where a sector model was used to determine ACS practice adoption and acreage reallocation under carbon incentive programs and a study by Plantinga and Wu (2002) which used an econometric statewide model to depict the economic response to an afforestation program and resultant co-benefits in terms of erosion and hunting days.

3.3.5.2.1.3 Routing analysis of more aggregate watershed implications

The analyses based on the site level biophysical simulators do not really address the total routing and fate of co-benefit related items. In particular further efforts are required to examine the consequences for the quality of adjacent air, surface water and ground water systems. Generally this is done with some mixture of observation and use of river basin, aquifer or air quality simulation models. Examples include the use of surface water hydrology models such SWAT (Arnold et al (1998), Srinivasan et al (1998)) as used in Atwood et al (2000)) or NWPCAM (RTI, 2000) as used in Bondelid et al(2001)).

3.3.5.2.2 Economic co-benefits

Estimates of economic co-benefits are needed in terms of income distribution, food prices, crop and livestock mix changes, aggregate productivity, food security, levels of exports/imports and employment among other things. Often this is done with sector modeling but other economic models may also be used to gain an estimate of the local and demographic induced impact (for a comprehensive example of such an analysis see Clarke (1997)).

3.3.5.3 Valuation of co-benefits

Finally we come to the topic of valuation of the rather diverse set of co-benefit. The questions at this stage are:

Do we need to develop values of the co-benefits and

How have people who have tried developed values plus are there value estimates that can be used.

3.3.5.3.1 Is it desirable to value co-benefits

From an economic standpoint a nontrivial question to ask is whether or not co-benefit valuation estimates should be developed. Co-benefits valuation requires that we examine many commodities or impact indicators, which are not subject to market values. In such cases often there is no direct and obvious valuation measure that one can use or construct based on observable market transactions as they have been influenced by a change in the abundance of the attribute.

For example if an ACS co-benefit involves enhancement of the population of an endangered species then there would likely be no groups whose activities would directly and totally reflect enhanced monetary value from enhanced species populations. Thus, one would have to value the enhanced endangered species preservation by looking at some willingness to pay measure for continued existence value of that species (through what is known as contingent valuation) or perhaps the money spent by people in traveling to see the species (the travel cost method). Both of these methods are discussed in Freeman (1993) and IPCC 2001.

The same sort of valuation difficulties arise for such co-benefit categories of: a) reductions in pesticide and other chemical concentrations in water, b) alterations in the distribution of income in rural areas, c) reductions or increases in the incidence of poverty and d) an altered balance of payments for a country's foreign trade account. Such valuation estimates can be quite difficult to develop and in fact have not been developed on a widespread basis that would geographically needed to apply to broad-based co-benefits valuation estimation. Furthermore, the valuation estimates that do exist are often point estimates. However, one would likely need demand curve estimates as a widespread GHGE program portends rather large increments in some co-benefits categories and the concept of diminishing values as more and more of a co-benefit is generated is probably inappropriate.

There is also the question as to whether or not the values once developed are relevant to certain types of decision-making. Such estimates are largely irrelevant to private market decisions as the economic values will not be reflected on the market and captured by the parties to the transaction. They also may be misleading in the policy/public decision making/public incentive design arena. For many years valuation of some of the co-benefits like induced income for water development projects has not been judged to be an appropriate addition to project cost benefit analysis. In particular when a project is developed, the resultant market implications have indirect implications both in the project region and outside the region where the project may cause altered activity say less mitigation in the energy sector. If one were truly doing global accounting, one would fully consider the indirect co-benefit implications of those actions in these other regions. Such effort is generally well beyond the scope of the effort undertaken and constitutes an unrealizable ideal. In turn, the argument has traditionally been made that only counting part of the indirect co-benefit's accruing from the project and not any of the indirect effects elsewhere would be misleading. Thus guidelines like the principals and standards for water projects (Water Resources Council, 1973, 1983) recommend that such accounting should not be included into the overall cost benefit calculus. See the papers by Stoevenor and Kraynick(1979) for more discussion.

One should also mention that valuation might not strictly be necessary. For many years we have known about the existence of these co-benefit categories but many studies have been done which have not attempted their valuation. It's often said that the job of the policy analyst is to reflect the multidimensional nature of the project benefits, costs and co-benefits providing him as input to the policy or private decision makers to in turn would implicitly apply their own values in arriving at a decision. Exercises to try to resolve all only co-benefit's values into a single summary measure of project desirableness, while academically intriguing, have not been implemented in many cases. Perhaps the bottom line is that co-benefits valuation estimates may not be fully necessary but it is valuable to define categories of co benefits, design useful measures for them and if possible report the aggregate magnitude of the types of the effects then apply valuation estimates if possible but still report a multi-dimensional set of project implications.

3.3.5.3.2 Prices for co-benefits

Nonmarket valuation of co-benefits is a very large subject. Freeman(1993) has a book on it and most resource economics texts well as hundreds of papers cover the subject. In terms of valuation of benefits, one needs to try to develop marginal estimates of how much change in the quantity of co benefit items alters societal economic value. In an ACS setting the most commonly used estimates are those generated by Ribaudo(1986) on the off-site cost of preventing erosion. However, standard estimates are not available for many of the categories nor is the notion of demand curve estimates reflecting lower valuations as the co benefits categories grow larger. McCarl et al (1999) and Plantinga and Wu(2001) use Ribaudo's estimates in an ACS setting. Feather, Hellerstein and Hansen(1999) discuss use of these measures in an ACS context at length.

3.3.6 How might we assess the comparative desirability of ACS?

Now we come to the ultimate economic issue discussed which involves the appraisal of the comparative desirability of ACS emission offset practices versus other emission offset practices or in other words just how important are ACS strategies. Much of the stage for this discussion has been set above. We treat this discussion in three parts: appraisal within the agricultural sector, appraisal in a broader economy wide international setting and dynamic components of the appraisal.

3.3.6.1 Appraisal within the agricultural sector,

From a strict conceptual viewpoint an analysis would need to proceed through a multiple step process.

- Farm level information needs to be generated on the costs of pursuing alternative practices and their GHGE consequences as well as estimates of co-benefits, which would occur as a consequence of that adoption. Information needs to be added on the monetary equivalent cost incentive needed to overcome the nonprofit obstacles to adoption i.e. the cost required to compensate the producer for bearing additional risk or overcoming other obstacles in that are required to make an the practice the one adopted.
- Information needs to be added to the farm level estimates on the transactions costs of program implementation, contract assembly and targeting.
- A sectoral level appraisal needs to be constructed which compares ACS opportunities with other agricultural GHGE offset opportunities based on practice cost and implementation cost across the total agricultural sector. In this analysis alternative carbon equivalent prices should be studied ranging from relatively low price levels ($0 to $5 per tonne) to relatively high levels ($200+) to estimate the relative importance of ACS in the portfolio of strategies used various prices and the ultimate potential at high prices. From this information should be fed back to step one for information refinement on attractive strategies and an iterative process possibly carried on.
- The GHGE accounting component of the sectoral appraisal needs to be as inclusive as possible covering sequestration and the influence of practice adoption on input usage, production, transportation, international trade and crop/livestock mix and the resultant net emissions of carbon dioxide, nitrous oxide and methane. This appraisal needs to consider the target region and regions where leakage may occur.
- Analyses need to the done incorporating a value for the co-benefits to see how that influences the desirability of the portfolio strategies chosen.
-

Studies may also involve an exploration of potential alternative targeting and incentive schemes in terms of program effectiveness, and costs.

McCarl and Schneider (2001) have done a strategy appraisal that considers a number of the above issues with the important exception of the transactions cost component (operating under the assumption that the transactions costs are equal for all opportunities). They examine the competitive economic potential of ACS strategies in comparison with biofuel, afforestation, manure management, rice acreage, irrigation water use, fertilization management and several other opportunities. The results are given in the competitive potential line in figure 1. Those results show that in the absence of transactions costs considerations that ACS strategies are highly competitive at low carbon equivalent prices. However they peak out relatively soon and later fall due to competition for land and the need for intensification in the face of reduced agricultural production. McCarl and Schneider also found that GHGE participation by agriculture has distributional implications favoring producers' at the expense of consumers' and total society. McCarl, Murray and Schneider (2002) extend this work to factor in saturation effects and find that saturation consideration favors emissions reductions over sequestration strategies but does not have that large of an effect. The results also show the rather obvious point that more strategies under consideration the cheaper the offsets and the more diverse the strategy choice portfolio.

The likely incidence of differential transactions costs across GHGE emission strategies could significantly affect the role of ACS in the portfolio.

3.3.6.1.1 Economy wide and international appraisal

Agricultural strategies are one component of a vast array of broader possible strategies. To assess comparative desirability one could unify the above described agricultural analysis with a broader analysis spanning the rest of the economy and possibly world. The scope however dictates that a more aggregate analysis be under taken. Such an analysis could be done by unifying the agricultural sector results in the form of an effective simultaneous supply curve of GHGE offsets given the carbon equivalent, energy and agricultural price signals from the rest of the economy then link that set of curves into a broader analytic framework as being developed under the Energy Modeling Forum (Weyant and Hill(1999)). Such an effort would improve the agricultural component assumptions in those studies, which generally have not tried to include sinks. In turn one would be investigating the comparative role of agricultural offset strategies in the context of actions that could be done in the total economy and global setting. Sohngen, Mendelsohn and Sedjo(2001) have pursued such an analysis considering the role afforestation may play in the context of the Nordhaus and Boyer(2000) DICE/RICE model. However, they ignore the transactions cost, saturation and co-benefits aspects of the problem as well as appraising a single strategy only. They find that sequestration does have a role in the total portfolio but does not relax compliance cost very much (at most a couple of percent) rather just displacing some roughly equally costly energy sector offsets.

3.3.6.2 Including Dynamics

The agricultural and total analysis frameworks above are presented without discussion of dynamic issues. However this is a key issue given the varying effects over time of ACS strategies, most notable saturation. To the extent possible dynamic analyses should be done looking at the dynamic role of agriculture and whether it is a bridge to the future as has been commonly discussed (Marland, McCarl and Schneider(1998, 2001) and Lecocq and Chomitz(2001) elaborate). This would include some analysis of the effect of different future carbon equivalent price trajectories.

4 Program and Policy Implementation

We now come to a second penultimate question in this manuscript which involves how one factors economic considerations into a sign of policies and programs to implement some form of participation by ACS strategies in the overhaul greenhouse gas emissions mitigation effort. Here we first will discuss the basic way a program can be implemented then later the target of the program.

4.1.1 Basic Approach

As has been discussed many times before (Stavins, 2001) a GHGE mitigation policy or program involving ACS strategies can be implemented along traditional lines

- Command and control procedures
- Taxes and subsidies
- Cap and trade with permitted emissions trading procedures.
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In addition in the face of co benefits and in congruence with the more general multi goal agricultural policy one could

- Incorporate additional incentives for ACS strategies in the traditional agricultural policy framework.

Naturally a mix of the above strategies can also be used.

4.1.1.1 Command and control

Following Stavins (2001) conventional command-and-control approaches to regulating the environment involve forms of limits directed at effluent measurements or practices. Command-and-control regulations do this by either

- allowing or disallowing particular practices or mixes thereof specify the method, and sometimes the actual equipment, that firms must use to comply
- setting uniform effluent standards for firms but allowing some latitude in how this target is met.

Such approaches typically allow little flexibility for compliance across or within firms force them to roughly equally share in the pollution-control burden, regardless of relative compliance costs. Holding all firms to the uniform targets can be expensive. Often the costs of controlling emissions vary greatly among and within firms due to physical configuration, location, and age of assets. Thus the appropriate technology in one situation may be very expensive and inferior to other practices. Tietenberg (1985) found that the aggregate costs of compliance relative to the least cost alternative ranged from 1.07 times as costly for sulfate emissions in the Los Angeles area to 22.0 for hydrocarbon emissions at all domestic DuPont plants.

Command-and-control regulations also tend to discourage innovation not allowing or encouraging introduction of technologies that might otherwise result in greater levels of control. Financial incentive is not present for actions exceeding control targets, and practice regulations can disallow adoption of new technologies. A business that adopts a new technology may be “rewarded” by being held to a higher standard of performance.

4.1.1.2 Taxation / Incentives

A second alternative is to pursue some form of taxes and or incentives. Such approaches involve taxes or reduction incentives directed at effluent measurements, practices or emission causing inputs. Such approaches send a price signal valuing the amount of pollution generated (ala Pigou, 1920). Consequently, these taxes or incentives stimulate the firm to reduce emissions to the point where marginal abatement cost equals the tax rate or adapt practices that contribute to emissions reductions.

A challenge with such taxes and incentives is identifying the appropriate tax or subsidy rate. Ideally, the emissions tax should be set equal to the market clearing price between the marginal benefits of cleanup and the marginal costs of cleanup, but Stavins(2001) argues that policy makers are more likely to think in terms of a desired level of cleanup, and do not know the compliance cost schedule. Similarly the practice subsidy should reflect the value of the emissions offsets. Such approaches do not typically discourage one from being cleaner in emissions than a given target level. However they do still suffer from the one firm at a time approach and do not necessarily allow the cheapest actors to do the most mitigation.

Such an approach has been used on a practice oriented basis in agricultural policy where for example erosion practices have been cost shared and CRP prices have been announced then participation solicited. Such approaches can suffer if practice oriented from inaccurate targeting, particularly if they are on the practice or inputs side and the emissions are not a relatively constant function of the inputs or practices used.

4.1.1.3 Cap and trade market

By far the most popularly discussed mechanism in the context of the GHGE mitigation context is the private emissions trading market. Such a market would be structured within a country with an overall society wide emissions cap set at approximately the right level of emissions. Emission permits would then be allocated or auctioned to the emitting community. These permits by their very nature would be tradable allowing emitters for which the costs of emissions reductions is relatively expensive to purchase permits from emitters who could generate offsets more cheaply. Such trades could take place domestically or internationally and could involve direct negotiations between emitters or the use of market intermediaries - brokers. Then through such market actions the emissions price would be "right". ACS strategies would participate in such a market by expanding the available stock of market permits and procedures would need to be in place to issue permits based on ACS actions.

This market might not be as broad as implied by the above paragraph. There also could be the possibility of alternative organizational forms where is substantial variability in the structures of the markets that have arisen to allocate pollution rights. Four main market forms are identified: exchanges, bilateral negotiations, clearinghouses, and sole-source offsets. Again the trades could be based on predicted GHGE emissions or on ratings tied to particular practices or input usage.

4.1.1.4 ACS incentive in traditional agricultural policy

Congressional deliberations and actions during 2001 seem to indicate that ACS strategy subsidies could be included within the context of the total United States agricultural program. The agricultural program policy agenda has been pursued for many decades and is not and will not be oriented solely toward a single goal like creating GHGE offsets. Program design includes pursuit of a multidimensional set of attributes including farm income improvement, price supports, regional income redistribution, and environmental improvement. Inclusion of ACS practices in such programs portends a total bundle of incentives that could well be larger than incentives that would arise under even relatively high carbon prices. For example one can compare a breakeven price that could render payments under an average ACS rate of 0.23 tonnes per acre with numbers like the $10,000 per farm intermediate payment level under the potential Harkin legislation. In that case with a 500 acre farm van to achieve the $10,000 payment would take carbon price of $87 per tonne which is in excess of what most people consider would happen in the near term.

The inclusion of such elements in the overall farm program are an acknowledgment of the co benefit findings of McCarl and Schneider(2001) and Plantinga and Wu(2001) that shows that significant income and environmental improvement co benefits occur. The inclusion in the general farm program would also most likely be done on a practice subsidy and monitoring basis without monitoring or measurement of the quantity of greenhouse gases being sequestered. Such an approach might help lower transactions costs as the farm program general structure is already in place and the marginal costs of stimulating the carbon benefits might not require a great deal of additional transactions costs. However this would imply that if GHGE offset accounting were still needed on an international basis, that estimation, measurement and monitoring would still be needed but perhaps more along the lines of the exercises pursued behind the U.S. submissions.

Farm program actions may also be encouraged by the nature of the U.S. participation in the world trade negotiations. International agricultural trade negotiations distinguish basically two types of domestic support: support activities that directly affect domestic supply and prices and thereby international trade are placed in the "Amber Box" and support activities that have no or minimal distorting effects on trade are placed in the "Green Box". Environmentally oriented support, which is not linked to production decisions belong to the Green box category. In the trade negotiations countries are committed to reduce Amber Box measures. ACS practice subsidies may provide a Green Box way to provide support while still achieving other policy goals if as Nelson (2002, pg 15) reports "they require producers to meet clearly defined specific conditions related to production methods or inputs. The amount of the payments shall be limited to the extra cost or loss of income from complying with such conditions".

4.1.1.5 Mixed market

Certainly a mixture of the above policy approaches could be used in implementing a program. Perhaps the most likely and even appropriate programmatic implementation for ACS practices would involve a mixture of the above private market and government program forms. For example, one might have government borne monitoring, certification and perhaps assembly of sales groups deflecting some of the transaction costs off of the private market in an actions motivated by the social worth of the co-benefits realized. In particular the co-benefits largely involve the income distribution and resolution of pollution problems. Both of these items are not subject to a market so their value would not be reflected upon the private market regarding the GHGE outcomes from ACS practices. However these items are judged to be valuable in the general policy formulation process. Government assumption of some of transactions costs of ACS related GHGE market participation could reflect the societal values on market decisions and create more nearly optimal decisions providing the level of participation was appropriate. The basic concern than would be the development of an appropriate balance between the costs of government participation and the value of the co-benefits realized which would be external to the private carbon market.

4.1.2 Practice or Emissions – the target of a program

The primary approach to offering environmental improvement incentives in agriculture has been to offer incentives tied to farming practices. This has largely been done by providing incentives based on predicted environmental performance of a set of management practices. For example, Canadian energy companies offered to pay Iowa farmers to adopt minimum tillage or retire land into grasslands as part of a GHG program while CRP has paid for land retirement with prices varied by region targeted in part toward regions with environmental problems and toward lands meeting environmental criteria. It is well known that providing incentives based on practices can lead to inefficient management choices as it faces targeting problems (Nielson, 1986, Antle et al 2000), reduces farmer flexibility, can be difficult to monitor and very costly to implement (McSweeny and Shortle 1990).

On the other hand aiming a policy toward amount of GHGE offsets can be difficult. Carbon load will never be perfectly known and can only be estimated not observed and are thus difficult and costly to monitor or predict, making it hard to implement direct regulation.

Ultimately the approach comes down to the establishment of a tradeoff between lost precision of practice and input cost targeting and the lesser transactions cost of practice targeting. This tradeoff is simple if the emissions are a relatively constant function of practices or input use but is difficult if the correlation is spatially heterogeneous as the evidence in McCarl (1998) and Antle (2001) suggests.

4.1.3 Handling impermanence, leakage, additionality and uncertainty

Program design requires the active consideration of provisions for handling the ACS characteristics of impermanence, leakage, and uncertainty in which may differentiate them from other offset opportunities as well the baseline issue of additionality. These may be handled through a number of approaches as discussed below. The simplest approach may involve adoption of discounting procedures, which reduce either the eligible offset, or the price paid for the offset to adjust for ACS practice characteristics.

4.1.3.1 Impermanence

ACS practices may yield GHGE offsets, which can be considered impermanent from two viewpoints.

- The GHGE offset gains realized from such projects do not continue at the same annual offset rate over the long term as the soil uptake of carbon exhibits saturation. In particular after 10-20 years West and Post find uptake rates fall substantially.
- Carbon is stored in a volatile form where discontinuation of ACS practices can lead to its release back to the atmosphere.

These differing characteristics of sequestered carbon relative to emissions offsets imply there may be need for an adjustment in either the payment mechanisms or the price paid for sequestration offsets. Four programmatic or policy approaches can be taken.

- Tonne-year accounting can be adopted where the developer of an ACS project is paid the full value of the GHGE offset when it is developed but also assumes liability that developer will need to purchase GHGE offset permits if and when the ACS practice is discontinued the sequestered carbon is emitted. Such a practice has been widely discussed (see the IPCC LULUC report) and embodies the Feng, Zhao and Kling(2001a,b,2002) pay as you go system.
- Short term contracts may be employed where one makes an agreement with farmers to use ACS practice developers for a fixed duration and pays a discounted price as suggested by Columbia(2000) in the KP negotiations, Mitchell and Bennett(2000) or in the variable annuity scheme of Feng, Zhao and Kling(2001a,b ,2002).
- Carbon annuity contracts may be used as proposed by Feng, Zhao and Kling(2001a,b,2002) where one places money can equivalent to the value of carbon at time to carbon is generated into an escrow account and gives the ACS practice developer rights to withdraw the annual earnings from that escrow account as long as carbon is sequestered and if that carbon ever volatizes then returns to money to the original purchaser.
- A discounting concept based on net present value of the offsets may be employed as suggested in McCarl and Murray(2002) and McCarl, Murray and Schneider(2002) where one uses present value calculations to developed a rating for the value of carbon relative to emissions and then discounts the price paid accordingly. For example McCarl and Murray derive a case where a saturating ACS practice that stops uptake after 20 years and then volatizes the carbon is worth 36

percent as much as a permanent emission offset.

4.1.3.2 Leakage

Agriculture is widely regarded as one of the most highly competitive economic sectors within the economy. Agricultural markets are truly global with commodities moving freely throughout much of the world. As such leakage is certainly a concern. Localized projects will stimulate additional economic activity domestically or internationally. Such markets portend substantial leakage possibilities. For example Wu estimates CRP program implementation stimulated leakage in the 20 percent range while Wear and Murray show leakage estimates in the 85 percent range from for a forest preservation case. Leakage discounts are likely to be needed either in terms of standardly applicable rates or in terms of requirements of leakage rates estimation exercises within project appraisals. The formula and approach in Murray McCarl and Schneider should provide a starting point for handling this issue.

4.1.3.3 Uncertainty

Agriculture is a sector of the economy, which is characterized by pervasive uncertainty in yields of commodities, and this is certainly going to carry through to the annually produced volume of GHGE offsets from ACS practices. As such the issue arises as to how the offsets from ACS practices might be treated in the marketplace and what level of offset could be "confidently" counted on to occur.

As discussed above Sampson(2002) has generated a list of alternative risk management schemes. Perhaps the most readily implementable elements involves reporting not average carbon but rather some lower confidence interval level that will be met or exceeded a given percent (e.g. 90%) or more of the time. This could also be implemented by generating some average assumption about the coefficient of variation on sequestration activities and then applying that assuming say a 15 percent or more discount from the average numbers reported to reflect for uncertainty. However one should note if offsets are aggregated through brokers and that the uncertainty is likely to be mitigated by diversification so a one size fits all discount may not work. Program design would also a number of Sampson's other recommendations including design standards, practice monitoring , practice continuation obligation contracts, research pools of offsets, and insurance instruments, all of which help to help manage risk.

4.1.3.4 Additionality

One of the often-discussed issues in the context of international negotiations surrounding the KP has been the concept of additionality. The additionality related discussion implies some estimate is needed on how much of an ACS practice would have adopted under business as usual. Additionality is concerned when the region where a project is being proposed has had substantial adoption of the ACS practice before any greenhouse gas programs were implemented. In such a case then some average discount for the region may need to be taken to reflect natural ACS practice adoption. To avoid contentious issues with private landowners in a standard discount would probably need to be generated and applied to all projects in the region in the form of a percentage discount on potential offsets. For example if in the long term 0.1 percent of land has gone into conservation tillage each year and if the ACS proposal is to switch 20% of the land over a 20 year period then perhaps a 10 percent discount on the GHGE offset would be applied. Such details need to be considered and perhaps required in appraisals.

4.1.4 Implementation Prospects and Obstacles

The above evidence shows agricultural carbon sequestration may have important implementation prospects. Important questions, which then arise, are :

Will farmers adopt ACS practices?

Will there be important obstacles to adoption?

4.1.4.1 Implementation and Adoption Prospects

The adoption prospects are probably good if the incentives are running. For example in 1983 a one year land retirement program was implemented which was called the Payment In Kind(PIK) program. In that year a tremendous acreage was idled between the effects of PIK and the conventional set-aside program. The 1998 USDA Agricultural Fact Book reports "In 1983, the sharp decline in cropland harvested was the result of “PIK” (payment-in-kind), a USDA land retirement program that paid for the land retirement with surplus commodities. The idle acreage in 1983 included nearly 49 million acres in the PIK program and more than 29 million acres in the Acreage Reduction Programs and Paid Land Diversion programs.". Collins(2001) indicates “Farm policy was fairly benign during much of the 1970s as exports boomed but, again, high supported prices and rising yields led to the largest annual land retirement program in history in 1983, the Payment In-Kind (PIK) Program”.

This shows farmers to be quite responsive as it indicates around 75 out of a pool of about 350 million acres responded in that one year. This indicates that farmers can respond strongly in the short run and portends a possible important short run role of ACS strategies, which is not hindered by impermanence characteristics. Namely ACS strategies provide a short run way of offsetting GHGEs while longer run technological developments continue. This is the bridge to the future argument made in Marland, McCarl and Schneider(1998,2001) and Lecocq and Chomitz(2001) among other places.

4.1.4.2 Obstacles

While the ACS strategies offer the possibilities for gains in terms of the GHGE agenda there are also potential obstacles. For example, in an appraisal of the possibility of adopting alternatives to slash and burn agriculture in Sumatra Tomich et al(2001) investigate a number of potential obstacles. These include items discussed above involving individual profitability, and risk attitudes. Beyond this Tomich et al treat regional employment possibilities, household food security, cash flow constraints, input supply markets, output demand markets, labor availability, rural financing markets, information on practices, consistency with existing regulations, local environmental issues, land property rights, bias of program design toward large units, and social collaboration. In examining these issues in the Sumatra setting they point out that conflicting property right based claims to land to make it difficult to get land management changed. More generally there are a number of prospective institutional obstacles, which may have to be considered in progress policy design, and which may also contribute substantial risk to implementation.

5 What do we know

From a research perspective the overall field of agricultural soil carbon sequestration is relatively young. In addition there are continuing, significant ongoing developments in the soil science and related technical fields involving carbon measurement, management practice/carbon interrelationship experimentation and simulation modeling. As a consequence the economic related research findings are

- based on preliminary carbon sequestration quantity estimates
- done in relatively localized settings under specialized, but not generally applicable assumptions
- often based on studies done for entirely different purposes and thus are not based on full information about carbon sequestration issues.
-

As a consequence virtually all the economic issues reviewed above are in need of research. However, a number of findings have been emerged that appear incontrovertible. Thus, in this section we present a list of findings, which we believe are widely applicable, and a non-prioritized set of research issues, which are important to be pursued.

There are a number of possible findings, which are based on either theoretical examinations of the situation, the published research, or analyses that have been done. They can be separated into economic and technical findings

5.1 Technical Findings

A set of basic findings arises from soil scientists as largely covered in the books by Lal et al (1998) and Follett et al (2000) or the IPCC reports

- Changes in agricultural practices can enhance the amount of GHGE absorbed into agricultural ecosystems
- The amount of carbon in conventionally cultivated agricultural soils has declined over time
- The more intensive the tillage the more carbon is released
- The amount of carbon that can be restored into a soil depends on soil characteristics as well as the local climate, cropping pattern and tillage practice / land history used before the restoration effort begins.
- Soil uptake of carbon after practices are changed is higher at first then saturates
- Not all practices have equal effects on all soils as cases have been

found where changes in practices, which work elsewhere, may not make a contribution in select cases.

- Virtually all of the carbon sequestration practices have other implications in terms of greenhouse gases both reducing emissions due to conserved fossil fuel and possibly increasing emissions due to uses of fertilizers and other petrochemicals.

5.2 Economic Findings

A set of economic findings has also arisen largely as reviewed above where below we site at least one case where the finding arises

- Low levels of ACS can be cheap but extremely high levels will be expensive (Pautsch et al 1999, Antle et al 2000, McCarl and Schneider (2001)).
- Changes in practices do not generally occur in the absence of incentives (Antle(2000), Kurkalova, Kling and Zhou(2001)).
- Budgeting of costs of implementing alternative practices is a starting point but only provides a lower bound as the cost of inducing adoption. The incentives required may need to be greater than the net change in profitability to offset increased risk, compatibility with firm resources, management requirements, and willingness to change, risk aversion, lack of information, etc. (Kurkalova, Kling and Zhou(2001)).
- Changes in practices that yield carbon also have environmental and economic implications(McCarl at al (1999), McCarl and Schneider(2000,2001), Plantinga and Wu(2001)).
- There is a substantial difference between carbon potential and the amount of carbon sequestration that is economically justified at any given price with the potential largely involving the maximum amount of carbon that can be sequestered if one was willing to pay a virtually unlimited amount to get that carbon (McCarl and Schneider(2001)).
- Program implementation and targeting costs money and can vastly change program results, program effectiveness and cost per unit (Stavins(2001)).
- Agriculture is likely able to cope with the effects of a carbon program without severe dislocations in food production or prices(McCarl et al(1998), USDA , McCarl and Schneider(2001)).
- Leakages are likely to happen due to land competition and market forces (Barrett(1994), Stavins(2001), Murray, McCarl and Lee(2002), Lee et al (2002)).
- Across the array of potential agricultural emission reduction, substitution and offset alternatives, there are alternatives with substantially different economic potential some of which are likely not to be very important strategies. The contribution of agriculture is likely through a mixed portfolio of emission offsets, not just an ACS program. A portfolio approach to greenhouse gas mitigation may

improve political feasibility bringing in the support of different advocacy groups (McCarl and Schneider(2001)).

- Responses to historical farm programs such as the PIK program show agriculture can respond quickly and thus be a quick source of offsets (Marland, McCarl and Schneider(1998,2001).
- Effects on the welfare of producers and consumers are likely to be in the opposite direction (McCarl and Schneider(2001).
- Integration of technical crop simulation and economic models is needed to carry out analysis (Antle et al(2001), McCarl and Schneider(2000,2001)).
- Different levels of analysis are needed with farm level analysis used for detailed examinations of on farm decision making, regional analysis to begin to appreciate aggregate response and national/ international analysis is needed to get an overall look at potential and relative importance (Bender and McCarl(1992), Antle(2001)).
- Agricultural emission offsets are in the large competitive with traditional agricultural production due to diversion of acreage, lower yields and/or higher costs(McCarl and Schneider(2001)).
- Transactions costs concerns arise in the implementation design (Stavins(2001)
- Sequestration credits are worth less than emissions credits due to volatility and impermanence especially if maintenance charges are needed(Feng, Zhao and Kling(2001a,b,2002), McCarl and Murray(2002)) but still can play a valuable role (Lecocq, F. and Chomitz, K. 2001).

6 What are some high priority economic research items in need of investigation?

Now suppose return our attention to some high-priority economic research needs. We will separate these into a number of classes

6.1 Costs of producing greenhouse gas offsets

There is need to assess the costs of producing greenhouse gas offsets through carbon sequestration by inducing practice shifts including changes in cropping practices, tillage practices, and conservation measures. This includes estimation of the costs of getting changes in practices to occur across a wide geographic scope and spectrum of land uses and conditions. This analysis would yield information on the economic potential of sites and supplement the technical potential estimates arising in books like the two by Lal and associates. The information should also contribute in determining the characteristics of sites on which it is likely that sequestration makes the most sense or conversely the sites on which sequestration would be very expensive to carry out.

Principally a broadly based set of case studies are needed to develop information on costs of emissions offsets across a number of regions of the globe and opportunities including practice implementation on crop land, degraded lands, grass lands, range lands, and pasture lands. The should consider a number of the applicable processes practices including tillage changes, land use changes, management alterations, and crop mix changes among others. In the context is carrying out these case studies and number of aspects of the problem need to be considered as listed in the next section.

There are also special conditions that merit more in depth careful studies. These include

- Investigations of adoption decisions and the incentive levels above and beyond net income differenced required to stimulate adoption. Careful field level studies of individual farming and adoption decisions will be a useful first step.
- Regional studies involving meta-analysis addressing how the cost of different opportunities and likely carbon impacts vary across space, climate and practices are needed.
- Broader level aggregate economic studies are needed to appraise the aggregate effects of market feedback arising in the product and resource markets on the economics of practice shifts and the resultant leakage.
- Methodological investigations are needed on how to gain consistency, transfer information and insure validity between field level analyses and more aggregate investigations.

6.2 Cost of Program implementation

There is a need to investigate incentive, targeting and market structure program design issues in terms of the resultant implications for efficiency of programs and transactions costs.

6.3 Co-benefits of Soil Carbon Sequestration.

There is a substantial agreement that the adoption of practices to sequester soil carbon will also yield additional environmental benefits in the form of reduced soil erosion, improved water quality, other greenhouse gases, provision of wildlife habitat, etc. Likewise, there may be "co-costs" in the form of expanded pesticide use, irrigation water use, effects on other greenhouse gases, etc. A comprehensive assessment of soil carbon sequestration needs to assess the benefits and costs of these factors. Efforts needed are

- Specific case studies relating to individual geographic areas, practices and/or categories of co-benefits and co-benefits.
- Aggregate information on the likely co-benefits and costs of carbon sequestration across a variety of impact categories and a wide range of geographic areas and farming practices also needs to be provided including both descriptions of the magnitude by category of items affected and the valuation thereof.
- The way that co-benefits might justify a subsidy above and beyond market processes so as to stimulate development in less-developed

countries as well as possibly capturing the value of some of the publicly gained co benefits so as to avoid market failure in the private emission offset markets.

6.4 Leakage of greenhouse gas emissions

There is in need to examine leakage at an aggregate level to determine how adoption of carbon sequestration influences use of other activities such as livestock feeding, crop mixes in other regions, international trade and production by trading partners. These changes may induce increases in greenhouse gas emissions. This "leakage" effect is important to understand and quantify.

6.5 Comparative Importance of Carbon Sinks

There is the need to investigate the proper role of carbon sequestration as one of the possible strategies that can be used to off set emissions in terms of its desirability versus other possible options integrating considerations of offset cost, implementation cost and co-benefits. Needed efforts include

- The role of agricultural (or other) sinks relative to emission reductions in other sectors. This work would further pin down the desirability of carbon sequestration in comparison to emission offset strategies and the practical potential of soil carbon sequestration identifying sites and systems with high implementation and economic potential.
- There is a need to integrate dynamics, saturation and volatility in the appraisal of the appropriate role of soil carbon sequestration versus other possible emission offsets over time.
- There is a need to do an analysis of how important agricultural greenhouse gas offsets are in the context of the total economy.

6.6 Economics of Monitoring and Verification

Verification and monitoring of soil carbon changes will be costly. The choice of policy design, specifically with respect to what variables will be is likely to depend largely on the cost of monitoring alternatives.

- Assess the costs of current and new technologies.
- Develop/assess procedures for design of monitoring and verification systems establishing a tradeoff between the costs of the monitoring and verification, the conduct of computer simulation and the foregone accuracy under program implementation.
- Development of linked biophysical simulation, economic appraisal system. There is a need to develop a linked integrating a biophysical geographic based simulation for carbon sequestration and an economic analysis system or systems which can reliably function across different scales of analysis (on a farm, in a region, nationally and internationally).

6.7 Protocol for a thorough appraisal

There is need given all the discussion above and the fundamentally needed nature of applied studies for a protocol on what a study should cover and how this coverage might be achieved. Here we present a trial protocol

Case studies should go through a number of steps. Here we present a list of suggested steps and items to consider under each

Step 1 Appraisal of GHGE offset potential

- a) List the practices that could be used
- b) Estimate the GHGE offset quantities stimulated by each practice in terms of the following
    - a. Estimated amount of carbon sequestered over time. For this appraisal the following approaches could be used
        - i. Simulation of GHGE increment using process modeling
        - ii. Estimation based on results of others employing
            1. Experiment station results on GHG increment
            2. Estimation based on expert appraisal
            3. Estimation based on literature based extrapolation such as use of IPCC estimation procedures or other studies
            4. Possible adjustments for regional climate
        - iii. Estimation based on native soil carbon content and an expert opinion or literature based estimate of the percent of the carbon that can be restored
        - iv. Augmentation of the estimate from i-iii with an estimate of the above standing biomass only counting carbon in residence for more than one year
    - b. Estimated GHGE emissions offset and or stimulated in carbon equivalent terms. Here separate on and off farm accounts should be reported on the emissions saved caused by input use alterations by practice accounting for
        - i. reductions in fuel usage for marketing, production and processing and embodied carbon.
        - ii. alterations in nitrogen use and estimate of embodied carbon equivalent nitrous oxide emission alterations plus carbon emitted in fertilizer manufacture.
        - iii. direct emissions caused by first order substitution for altered product mix (if biofuels are being produced this will be negative, if residues are being returned to the soil that were burned for fuel

or used in feeding animals this would contain some estimate of the emissions embodied in using those substitute products).

The IPCC good practice guidelines contain useful estimation procedures for developing estimates in the first two categories..

The over time aspect of the estimate should consider

- i. Time profile of GHGE emission offset storage by different practice including time to saturation estimate
- ii. Volatility "Impermanence" characteristics in terms of future releases through harvest, reversion of traditional practices, etc and likelihood this would occur and timing if it is likely.

Step 2 Account the farm cost of getting practices adopted. Here one would estimate costs arising in three categories

- a. Any cost increase (or decrease) over existing practices
- b. Any lost yield and revenue over existing practices
- b. Any additional adoption cost incentive estimates (training, extension, insurance etc)

Step 3 Develop estimates of discounts to be applied. These would follow the discussion in the section on these items under the Program and policy implementation above

- a. Leakage estimates -- Estimate the increased GHG emissions (or reduced sequestration) off project site that are caused by the action on the project site. This can be expressed as a proportion of the direct onsite credits. Possible approaches are
  - i. Use benchmark measures from published economic studies
  - ii. Use formula from Murray, McCarl and Lee.
  - iii. Develop estimates more specific to the location and practice at hand. These alternative estimates should be estimated using credible methods based on economic principles of market behavior.
- b. Saturation and impermanence effects -- Estimate the decrease in relative value of the ACS activities caused by need to pay maintenance cost of loss through volatization.
- c. Uncertainty discount -- Develop mean and 90 % confidence interval for expected GHG effects (preferably statistical)
- d. Additionality discount -- - Develop estimate of regional adoption of practice under business as usual and accompanying per project discount

Step 4 Develop transactions cost estimates. This should embody the estimates of putting together a 10,000 tonne per year lot. This should include cost components for

a. Initial assembly of parties to the contract

b. Measurement and monitoring costs

c. Annual payment dispersal costs

d. Annual keep group together cost estimates

e. Additional adoption cost incentive estimates (training, extension, insurance etc)

f. Procedures for and cost of risk/liability for adverse outcomes

Step 5 Develop estimates of economic scale effects.

a. Estimate nature of supply curve as higher prices were paid to practice adoption and the costs thereof.

b. Estimate competitive effect of simultaneous consideration with other GHGE offset strategies (would biofuels or afforestation compete for these lands).

Step 6 Develop an adoption obstacle appraisal by practice. This should include

a. Consistency of practice with prevailing property rights including any cases where there are multiple claims to lands to be treated.

b. Targeting possibilities and way of getting money to producers.

c. Suggested liability rules for shortfall and enforcement costs.

d. Liquidity constraints for practice implementation

e. Appraisal of possibility of assembling marketable quantity of offset (10,000 tonnes)

Step 7 Private market cost per tonne estimation. Add up costs of items in 2,4 and 5 divide by discounted carbon equivalent gains from set 1 adjusted by discounts in step 4.

Step 8 Co – benefits estimates. Construct multi dimensional appraisal of effects on income distribution , environment, food security and other valuable items.

Step 9 Public participation, cost and adjusted private market. Estimate public role in deferring transactions costs if likely and adjust downward private costs. Also if possible and appropriate indicate public value of co benefits.

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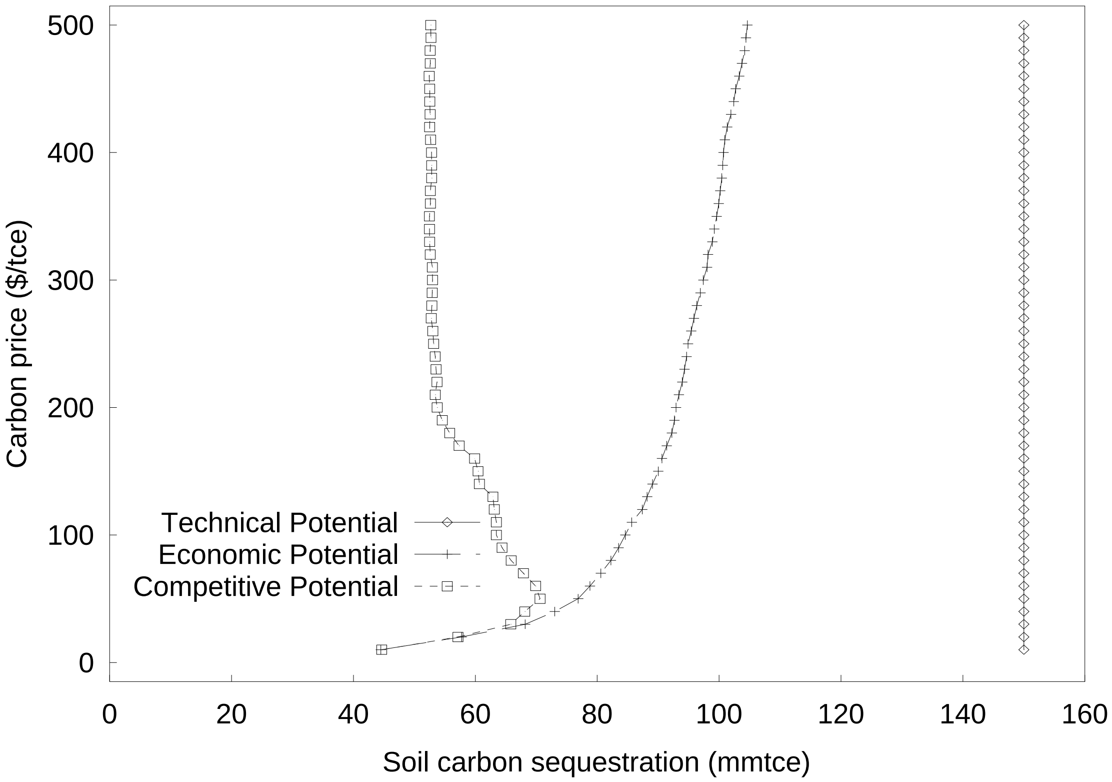

Fig. 1. Measures of soil carbon sequestration potential on U.S. traditional crop and pasture land. The technical potential represents the annual physical limit on soil carbon sequestration and was computed by changing ASMGHG's economic objective function from solving for the international agricultural market equilibrium to maximization of soil carbon sequestration. The [single strategy] economic potential shows the soil carbon sequestration response when only soil carbon is regulated. The competitive [economic] potential shows the soil carbon sequestration response when all agricultural GHG accounts are regulated simultaneously. Source McCarl and Schneider(2001).