

**Harvesting the Greenhouse through Altered Land Management:  
Economic Potential and Market Design Challenges**

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Carbon sequestration in agricultural and forest soils as well as standing trees has received substantial attention within the policy, energy, agriculture and forestry (AF) communities. Expanded concern arises from a combination of six principal forces:

- 1) Greenhouse gas (GHG) links to projected climate change,
- 2) International agreements as manifest in the Kyoto Protocol,
- 3) International pressures to reduce emissions,
- 4) High-cost emission offsets in other sectors of the economy,
- 5) Congruence of carbon sequestration activities with other AF related societal desires like water quality and income distribution, and
- 6) Potential emergence of a GHG offset market.

This interest is beginning to stimulate U.S. policy action with bills being introduced in Congress and discussions in both environmental and agricultural agencies regarding policy and/or program design. Many factors need to be considered in formulating appropriate policy and programs. Substantial literature is emerging regarding soil science and forest management aspects of and potential for carbon sequestration (see Lal et al., Follett et al., Intergovernmental Panel on Climate Change-IPCC [1996, 2000, 2001]). However, while this interest is founded in the technical potential that AF might generate substantial offsets, the real degree to which AF producers might meaningfully participate depends on key economic and market implementation issues. In this paper we will examine such potential looking at

- 1) Economic potential for AF participation in a GHG market,

- 2) Characteristics of AF GHG emission offsets that must be accommodated in market design to achieve meaningful AF participation.

### **GHG Emission Mitigation in AF -- Concept and Technical Potential**

Before discussing economic and market implementation issues we will briefly review the mechanisms through which AF can participate as well as the magnitude of the technical estimates for participation potential. Following the arguments in McCarl and Schneider (1999, 2000a), AF may mitigate GHG emissions by

- Creating or expanding sinks to enhance terrestrial absorption of atmospheric GHGs (carbon sequestration);
- Reducing GHG emissions generated during AF operations;
- Providing products, which substitute for GHG intensive products and thereby displace emissions.

Each of these points will be discussed below.

#### **Carbon Sequestration**

Atmospheric carbon dioxide buildup is an important forcing agent behind projected climate change (Schlesinger, North, IPCC [1996, 2001]). Terrestrial carbon sequestration offers a possible way of reducing concentrations. Carbon dioxide is continuously exchanged between the terrestrial biosphere and the atmosphere.

Chlorophyllic plants absorb carbon dioxide through photosynthesis and use the contained carbon to build organic matter. Thus, carbon directly accumulates as plants grow. At the end of plant life, most of the organic carbon is quickly released to the atmosphere through microbial decomposition or through combustion. However, some of the carbon enters other terrestrial pools (organic matter in soil, furniture, etc.).

Scientists estimate that about 80 percent of global carbon is stored in soils or forests (IPCC, 2000) and that a substantial proportion of the carbon originally contained in soils and forests has been released due to AF activities and deforestation. Collectively these facts imply that there is substantial potential for AF activities to sequester carbon (Lal et al., 1998).

There are three fundamental physical processes through which the amount of carbon sequestered can be enhanced: (a) increasing the amount of carbon held in soils or trees; (b) decreasing microbial decomposition; and (c) decreasing combustion (IPPC (1996) and Paustian et al. (2001)). Management actions that result in soil and tree carbon storage include (1) expanding forested areas; (2) delaying the time of forest harvest; (3) increasing forest growth rates through enhanced silvicultural practices; (4) adopting agricultural practices that minimize soil disturbance and erosion, (5) increasing retention of crop or logging residue, and (6) maximizing water- and nutrient-use efficiency of crop production.

The IPCC and leading U.S. physical scientists have estimated the technical potential of such practices (Table 1). With a projected U.S. Kyoto Accord target in the neighborhood of 700 MMT<sup>1</sup>, these estimates suggest that there is technical potential for sequestration activities to cover a large share of the U.S. obligation.

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<sup>1</sup> The Kyoto Protocol would require the U.S. to limit net emissions to 1990 levels less seven percent (United Nations, Framework Convention on Climate Change) between 2008 and 2012. Using EPA emissions inventory data, such an agreement would imply annual carbon emission reductions of about 300 million tons relative to 1990 plus offsets for emissions growth by 2010 (which by linear extrapolation is around 400 million more tons) for a total in the neighborhood of 700 million tons.

## **Emission Reductions**

The IPCC (1996) estimates that globally agriculture emits about 50 percent of all methane, 70 percent of all nitrous oxide, and 20 percent of all carbon dioxide. Methane is emitted in AF through enteric fermentation of ruminant animals, anaerobic livestock manure decomposition, rice cultivation and termites. Possible abatement strategies include altering crop choice, livestock herd size, livestock feeding and rearing practices, and manure management. Nitrous oxide emissions arise from manure, legumes, and fertilizer use and can be abated by reducing livestock herd size and changing crop mixes and fertilization practices. Carbon dioxide is emitted from fossil fuel usage, mineralization of soil organic matter, deforestation, and biomass decomposition or burning. Emissions can be reduced by decreasing production fuel use, changing the allocation of land between crops, pasture, grass lands and forests, increasing forest harvest intervals, improving crop residue management, and restoring degraded land.

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 occur in developing countries while developed countries slightly increase their forest base (FAO). Developed country agriculture generally uses more energy, fertilizer<sup>2</sup>, and intensive tillage systems, resulting in higher fossil fuel based and soil carbon emissions, nitrous oxide emissions from fertilizer and nitrous oxide plus methane emissions from animal herds and resultant

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<sup>2</sup> Aggregate estimates of fertilizer consumption show developed countries using about twice as much fertilizer as developing countries (FAOSTAT).

manure. Forest management practices that offset emissions include reduced deforestation or logging, protection of forest reserves, and improved disturbance management with respect to fire and pest outbreaks.

### **Product Substitution**

AF products may replace fossil fuel intensive products. Two such product categories involve biomass for power generation and transformation into liquid fuels. Biomass combustion mitigates CO<sub>2</sub> emissions because it recycles carbon with most coming from photosynthetically fixed carbon taken from the atmosphere during biomass growth. For example, Kline, Hargrove and Vanderlan estimate that only 5 percent of the carbon emitted through hybrid poplar-fed power plants pertains to fossil fuels. Fossil fuel combustion, on the other hand, increases atmospheric carbon dioxide concentrations use, by 100 percent of the contained CO<sub>2</sub>. Liquid fuel transformation generates smaller offsets, but is still an emission saver.

Forestry products can also be used to substitute for fossil fuel intensive steel and concrete in construction (Marland and Schlamadinger (1997), Brown and Brown et al. elaborate). Finally, there may be gains from substituting cotton and other fibers for petroleum based synthetics.

### **Economic Potential for AF Generated GHG Offsets –Conceptual Issues**

An appraisal of the economic potential for AF generated GHG offsets entails four important matters, some of which will be considered in our study and some of which will be left for further needed research. These include

- 1) Factors that would cause an AF producer to adopt a strategy,
- 2) Appropriate appraisal scope,

- 3) Competition across alternative strategies, and
- 4) Multi-gas tradeoffs.

After discussing each we will provide empirical data on economic potential.

### **AF Producer Adoption**

While policymakers and other interests may desire certain GHG offset practices to be used in AF, it is the farm or forest operator who ultimately controls the practices employed. Farmers and foresters adopt those practices that maximize their well-being.

Well-being, however, is a complex good involving many dimensions such as:

- Practice profitability,
- Risk and uncertainty,
- 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 existing equipment complement,
- Willingness and ability to invest in new equipment required to employ the practice,
- Desire for environmental stewardship coupled with the environmental attributes of practice, and
- Need to perform in compliance with imposed regulations.

Some practices currently used by farmers and foresters are desirable from a GHG emission mitigation point of view. In such cases, the operator has judged the practice superior to other alternatives even in the absence of adoption incentives. However, in

other cases the desired practices are not used. To convince farmers to adopt such practices, regulations or incentives are needed. The incentives may be a mixture of direct (such as carbon related payments) and indirect (such as sequestration shortfall insurance, investment subsidies, training programs etc.) instruments.

Consider for illustrative purposes the adoption of no-till farming as opposed to conventional moldboard plowing. Discussions with farmers (see the comments of Bennett, 1999) reveal reservations about the adoption of no-till for such diverse factors as

- Potential yield losses due to slower warming of untilled soils during cool spring planting seasons
- Potential yield reductions due to other factors,
- Potential cost increases particularly for weed and insect control,
- Need to acquire new expensive equipment,
- Critical reliance on the effectiveness of chemical weed control compounds and the need for continued efficacy of weed control,
- Learning time to be effectively employ the practice, and
- Willingness on behalf of older farmers to switch practices.

All of these factors affect the magnitude of the financial incentives required to stimulate adoption. A lower bound on the needed incentive could be calculated as the net income lost due to yield loss (note yield gains are possible) plus the net value of any cost change. However, sole reliance on forgone net income is likely to understate the incentive level needed. For example, Babcock et al. indicate that nominally profitable practices may not always result in full adoption; and thus that incentives above and

beyond lost income may be needed. In developing policies, it is critical to recognize that farmers are unlikely to make practice changes simply because of technical potential. Incentives are needed to overcome direct income loss and other disincentives for adoption.

### **Appropriate Appraisal Scope**

Scope is an important factor in considering potential role of AF activities for GHG emission mitigation. One might appraise the economic potential at the farm level looking at the incentives needed to induce participation on individual parcels. However such appraisals are based on current prices and may thus be misleading. U.S. cropland amounts to approximately 325 million acres. The literature suggests an annual maximum potential for agricultural carbon sinks around one ton of carbon per acre of cropland through afforestation (Stavins). Using this maximum, total annual agricultural cropland based contribution to carbon storage may be bounded at about 325 million tons. Thus, cropping agriculture could not supply sufficient emission reductions to fulfill the Kyoto Protocol even if all available cropland and very large incentives were involved.

Mitigation programs that involve a substantial proportion of the agricultural acreage raises the issue of agricultural price levels. Large changes in crop acreage imply changes in total production and in turn market prices. As a consequence a sector-level approach is needed to include mitigation impacts on the traditional agricultural sector.

## **Competition across alternative strategies**

The economic and technical potential of certain AF GHG emission mitigation strategies are not independent of the level of other strategies. For example, the more cropland farmers allocate to biofuels, the less cropland available for establishing permanent forests or adopting friendly tillage practices. Complementary relationships also emerge. Farmers may supply corn for ethanol processing and at the same time sequester soil carbon through minimum tillage and offset emissions by reducing fossil fuel use. Thus simultaneous consideration of potential rather than independent appraisal would appear to be appropriate.

## **Multiple Gas Tradeoffs**

AF enterprises contribute to emissions of multiple GHGs. A crop-livestock farm releases CO<sub>2</sub> when combusting the fuel necessary to operate field machinery, emits nitrous oxide through fertilizer applications, releases methane through enteric fermentation from ruminant animals or as a manure byproduct, but possibly augments the soil carbon stock by using reduced tillage. Tradeoffs between these emissions may occur if, for example, more fertilizer is needed under reduced tillage or if usage of growth hormones for animals alters the required acreage to produce feed.

Multiple gasses can be considered using the global warming potential (GWP) concept. The GWP compares the radiative forcing of the various GHGs relative to CO<sub>2</sub> over a given time period (IPCC, 1996). The 100-year GWP for CO<sub>2</sub> equals 1. Higher values for methane (21) and nitrous oxide (310) reflect a greater heat trapping ability. Thus multiplying an emission quantity by the GWP forms a "carbon equivalent" measure after factoring in an adjustment for the molecular weight of carbon in CO<sub>2</sub>.

## **Economic Potential for AF Generated GHG Abatement –Empirical Findings**

Now we turn attention to economic estimates of potential although we do not have full accounting of the disincentives that are not profit related.

### **Methodology**

Following McCarl and Schneider (2001) we use AF sector modeling to estimate the economic potential for GHG mitigation under different farmer received carbon prices (i.e. market prices less brokerage fees and other transactions costs). At each hypothetical carbon price, our model solves for the new AF sector market equilibrium. The volumes of induced GHG net emission reductions as well as other impacts are computed as deviation from the zero carbon price baseline equilibrium. Our analysis simultaneously considers the total spectrum of U.S based AF responses to a net greenhouse gas mitigation effort as well as the complex interrelated nature of activities in the AF sectors. For example, use of a biofuel mitigation strategy could alter corn production and corn prices which in turn may impact exports, livestock diets, livestock herd size, and manure production as well as land allocation to biofuels and forests. The mitigation strategies involved are summarized in Table 2 and are defined in McCarl and Schneider.

Our model is a mathematical programming based, price-endogenous sector model of the agricultural sector (ASM - McCarl et al., 2000b, Chang et al. (1992)), modified to include GHG emissions accounting by Schneider and hereafter called ASMGHG.

Recently ASMGHG has been expanded to include data from a forestry sector model (FASOM-Adams et al., 1996, Alig et al., 1998). ASMGHG depicts production, consumption and international trade in 63 U.S. regions of 22 traditional and 3 designated energy crops, 29 animal products, and more than 60 processed agricultural products.

Environmental impacts include levels of greenhouse gas emission or absorption for carbon dioxide, methane, and nitrous oxide; surface, subsurface, and ground water pollution for nitrogen and phosphorous; and soil erosion. ASMGHG simulates the market and trade equilibrium in agricultural markets of the U.S. and 28 major foreign trading partners. Domestic and foreign supply and demand conditions are considered, as are regional production conditions and resource endowments. The market equilibrium reveals commodity and factor prices, levels of domestic production, export and import quantities, GHG emissions management strategy adoption, resource usage, and environmental impact indicators. ASMGHG was then repeatedly solved for carbon prices ranging from \$0 to \$500 per ton of carbon equivalent.

### **Estimates of Economic Potential -- Results**

Scientific evidence and the number of inquiries regarding AF GHG mitigation are growing rapidly. The data underlying this study, while the best available to us as at this point in time will be old and obsolete tomorrow and could even be improved by substantial efforts today. Consequently, we will not concentrate on specific empirical results. Rather we will highlight a set of general findings, that we believe are highly relevant to consideration of the potential for AF sequestration and to the extent possible, that rise above the flaws in the underlying data.

### **AF Emission Reductions are Cost Effective Particularly Through Sequestration**

Figure 1 shows the amount of carbon equivalent emissions abated at carbon prices ranging from \$0 to \$400 by broad category of strategy. Up to 326 MMT carbon

equivalent can be offset by AF means (Table 3). Low-cost strategies involve foremost soil carbon sequestration and, to some extent, afforestation, fertilization, and manure management. To place cost estimates in perspective one could contrast our findings to Weyant and Hill's (1999) multi-model study of non-agricultural Kyoto compliance costs sponsored by the Energy Modeling Forum (EMF). Across EMF studies, abatement costs vary with assumptions on emissions trading and because of different baseline emissions scenarios across models. In presence of carbon emissions trading among Annex I regions, primarily the developed industrial countries along with eastern Europe and the former Soviet Union, U.S. abatement costs were generally in the range between \$50 and \$100 per metric ton of carbon but reached as high as \$227. The costs of achieving particular GHG emission reduction levels were much higher without international trade in carbon emissions rights.

### **A Portfolio of AF Strategies Seems to be Desirable**

Many different GHG emission (GHGE) mitigating agricultural strategies are possible and a number are often individually advocated. Our results indicate that a portfolio of strategies appears appropriate. Figure 1 shows the usage of the major mitigation strategies over the total range of carbon prices. The results show a role for biofuels, forests, agricultural soils, methane, and nitrous oxide based strategies. Different strategies take on different degrees of relative importance depending on the carbon price level. While soil carbon sequestration peaks at around \$50 per ton carbon, biofuel offsets are not competitive for prices below \$80 per ton.

### **Reliance on individual strategies appears to be cost increasing.**

Sole reliance on agricultural soil carbon (Figure 2 – economic potential line) reduces, for example, 60 MMT carbon at \$30 per ton while consideration of the total portfolio achieves the same reduction at a cost below \$15 per ton (Table 2).

### **Difference Between Technical, Economic, and Competitive Economic Potential**

Contrasting technical, economic, and competitive economic potential can illustrate the impact of economics on GHG emission mitigation potential in AF. We graph such a contrast for three major strategies: agricultural soil carbon sequestration (Figure 2), carbon absorbed through afforestation (Figure 3), and carbon offset through energy crops (Figure 4). Estimates of technical potential ignore cost and resource competition and show if fully pursued one could offset about 75 MMT annually with agricultural soil carbon sequestration and about 270 MMT with both afforestation and energy crop related mitigation.

However sole reliance on technical potential does not give a clear picture of implementation potential. Rather the cost of achieving particular levels must also be considered. Agricultural soil carbon sequestration is the cheapest mitigation strategy among realizing about 85 percent of the technical potential for a relatively low carbon price of \$50 per TCE. Energy crops and afforestation are more expensive to implement but their ultimate technical potential is larger than that for agricultural soil carbon sequestration. At \$50 per TCE, the economic potential for these two options amounts to 10 percent or less of their technical potential. It takes carbon prices as high as \$1000 per TCE for energy crop related carbon offsets to get close to the technical potential.

Competition between different mitigation strategies also important and is illustrated through the difference between economic potential and competitive economic potential. For example, if growing energy crops were the only mitigation option (economic potential), about 150 MMTCE could be abated annually at a carbon price of \$200 per TCE. If other options were considered simultaneously (competitive economic potential), the contribution of energy crops diminishes to about 75 MMTCE or by about 50 percent due to competition for land and other resources. The afforestation sink exhibits a similar pattern. In case of agricultural soil carbon sequestration, however, competition among strategies leads to a declining abatement contribution for carbon prices above \$50 per TCE because the other strategies are dominant in that range diverting land and cause a need for more intensification which leads to a greater tillage intensity. This behavior demonstrates that higher carbon prices do not necessarily increase the GHG mitigation contribution of all strategies.

### **Adopting Mitigation Strategies Impacts Environmental Quality**

Many of the proposed agricultural mitigation actions (tillage intensity reduction, manure management, land retirement etc.) have long been discussed as strategies, which simultaneously improve environmental quality. Consequently, one may expect benefits in terms of erosion control, runoff etc., which are created simultaneously with emissions abatement. Table 3 lists changes in a few selected environmental parameters as carbon equivalent prices increase. For the most part, rates of nitrogen and phosphorous runoff as well as reduced erosion decline. Environmental co-benefits largely stabilize at prices around \$200 per ton. Higher carbon prices increase biofuel acreage at the expense of

traditional crop production. As prices for traditional crops go up, intensive crop production becomes more profitable but maintaining yield-reducing mitigation strategies becomes more costly. Thus, for carbon prices above \$200 per ton we encounter a mixed environmental response from the traditional crop sector. Total traditional acreage declines but emissions per acre partially increase.

### **Markets for GHG Emission Mitigation: Considering AF Characteristics**

Economic and technical potential are not the sole predictors of whether AF GHG mitigating strategies will be important. In order for AF GHG credits to be sold to a potential buyer, three major cost components must be overcome. Namely, compensation must offset

- a) Cost to adopt a practice as discussed above,
- b) Transaction costs borne by the producer to sell the commodity including any costs of required monitoring and verification that has to be undertaken by the producer, and
- c) Costs accruing to market intermediaries for assembling, marketing and certifying net emission reduction quantities.

On the other hand, if the sector receives subsidies from farm program or other environmental initiatives because of co-benefits that are generated by the AF GHG policies, then these payments will offset some of the costs.

To date, quantitative analysis of only the first of the three cost categories has been explored in depth as discussed above. The remaining costs and the issue of co-benefits are likely to be much more complicated. The reason for this is that markets for GHG credits, particularly those associated with AF, will face a number of unique

challenges. Even when compared other environmental markets, such as the sulfur dioxide case, AF GHG markets will face enormous challenges. There are (at least) eight characteristics of AF GHG markets that make such market particularly problematic.

1. ***Non Point Source*** – Emissions and sequestration are geographically wide spread. Quantifying credits and monitoring compliance monitoring will likely require some mix of mobile efforts, sampling, computer modeling, and remote sensing. These costs must be borne by either the market participants or market intermediaries.
2. ***Cost Heterogeneity*** – Implementation costs and resultant emission mitigation quantities vary geographically, even for the same strategy. Differentiating factors include land-use history, soil and climate conditions, and various others. Certification and incentive programs need to recognize this diversity to provide incentives where they are most likely to generate the greatest benefit per dollar.
3. ***Targeting*** – Designing programs to address problems with characteristics 1 and 2 is difficult. However, society has been designing and refining approaches to soil erosion and forest improvement incentives for more than fifty years in programs such as the Conservation Reserve Program. Offset market designers may wish to review approaches used in soil erosion, water quality markets, wetlands markets etc. in setting up rules and market practices.
4. ***Permanence*** – Soil and forest sinks saturate. Payments may be needed to retain the sequestered carbon after saturation. McCarl and Murray conduct a

net present value analysis on tillage change induced soil carbon gains. They find soil carbon to be worth 1/2 or less relative to an equivalent amount of sustainable emissions offsets. Grading standards may be needed to adjust for saturation rates across strategies.

5. **Leakage** – Actions in one place cause reactions elsewhere so less production here implies more elsewhere. McCarl examined afforestation incentives finding that large-scale conversions of farmland into forestland causes large counter movements of existing forestland into farmland. These unintended land conversions offset close to 50 percent of the carbon gained from afforestation. Grading standards may be needed to adjust for differential leakage potential across strategies.

6. **Costs of market intermediaries** – It is anticipated that the primary purchasers of credits in a CO<sub>2</sub> credit market would be large sources such as power plants. AF sellers, on the other hand, may be made up of many small farmers and foresters. Assuming a 1/3-ton per acre carbon potential, the purchase of one 100,000-ton lot of carbon mitigation credits would require assembling, monitoring and verifying performance across 300,000 acres or about 500 square miles. This task would involve about 600 producers given an average farm size of 500 acres. If such a market is to succeed, brokers will need to arise to negotiate between buyers and sellers. Assembly and coordination costs would certainly not be trivial. Alston and Hurd estimate the costs of distributing deficiency and loan rate payments to be about 40

percent of the money distributed. The size of these transaction costs could exclude small acreage producers.

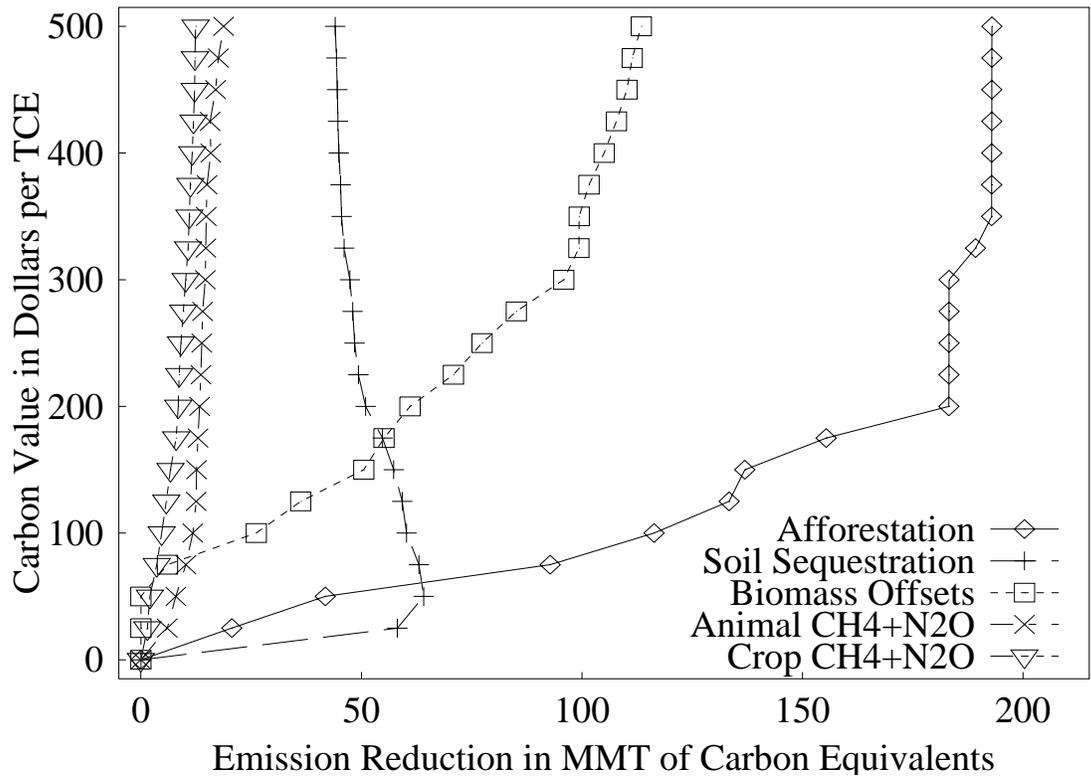
7. *Sweetening returns to reflect co-benefits* – Many AFS strategies generate co-benefits. Some strategies improve water quality or create more favorable patterns of rural income. Public subsidies or other environmental markets may exist or could be developed that favor strategies that generate co-benefits. These co-benefits would influence the optimal mix of AF policies and must be taken into account in designing markets for AF GHG mitigation.
8. *Property rights and existing practices* – Some producers already employ certain mitigation practices and have, therefore, already created a stock of carbon in their soil and forest stocks. This sequestered carbon could be released if the producer reverts back to traditional practices. What incentives should be created to ensure the continued sequestration of existing stocks of carbon? The answer to this question has complicated implications for both equity and efficiency.

If a market-based approach to mitigating GHGs is to succeed, each of the issues noted above must be addressed. Unlike markets for goods and services, the good that is transacted in environmental markets is defined by the regulations that create the market. Depending on how the rules are written, the resulting market can look like that for commodities traded on the Chicago Board of Trade, or like the market for used cars advertised in the local newspaper (Woodward and Kaiser 2000). However, it should not be assumed that a more efficient market is necessarily “better.” Efforts to increase

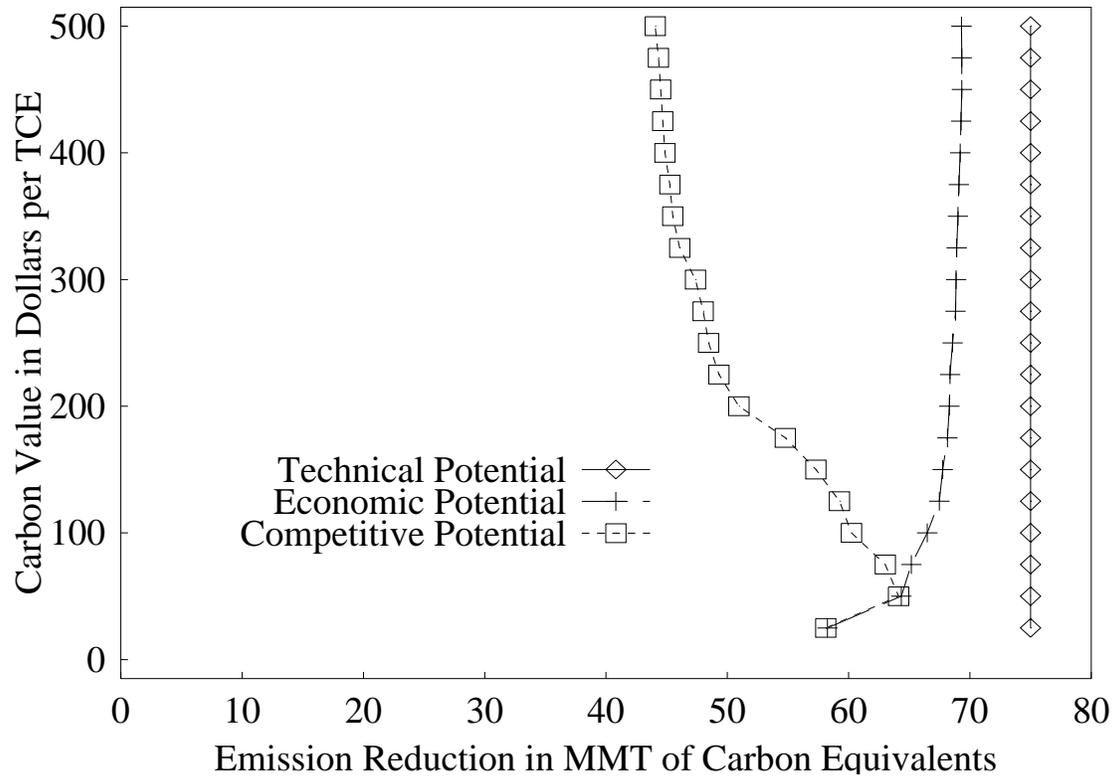
market efficiency may directly conflict with the need to monitor non point sources, accommodate heterogeneity, account for leakage and permanence, and recognize co-benefits. The greatest challenge for such markets may be finding a way to balance the need to create the appropriate incentives for each AF producer with the competing need to create a market that is not overburdened by transaction costs.

### **Concluding Remarks**

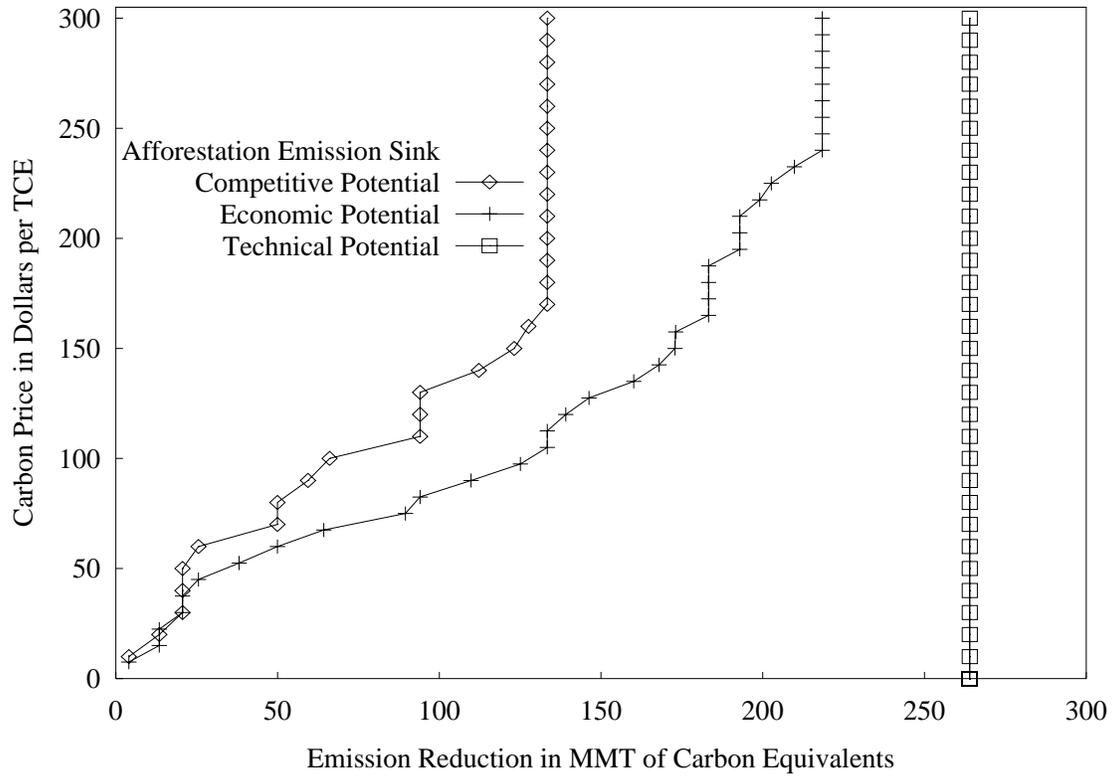
Agriculture and forestry offer the potential to mitigate a significant quantity of greenhouse gases through emissions reductions, biofuel offsets and carbon sequestration involving trees, land use change and tillage change. However practical economic potential is smaller than technical potential. Furthermore, there are a number of market design issues that need to be worked out to manage program transactions costs and place agricultural activities on an even footing with non-agricultural activities. We firmly believe that future agriculture and forestry producers will operate in a society that values GHG reductions and that these values will be expressed through markets and price signals. Determining how to best design those markets and predicting their real potential are important tasks for future research.



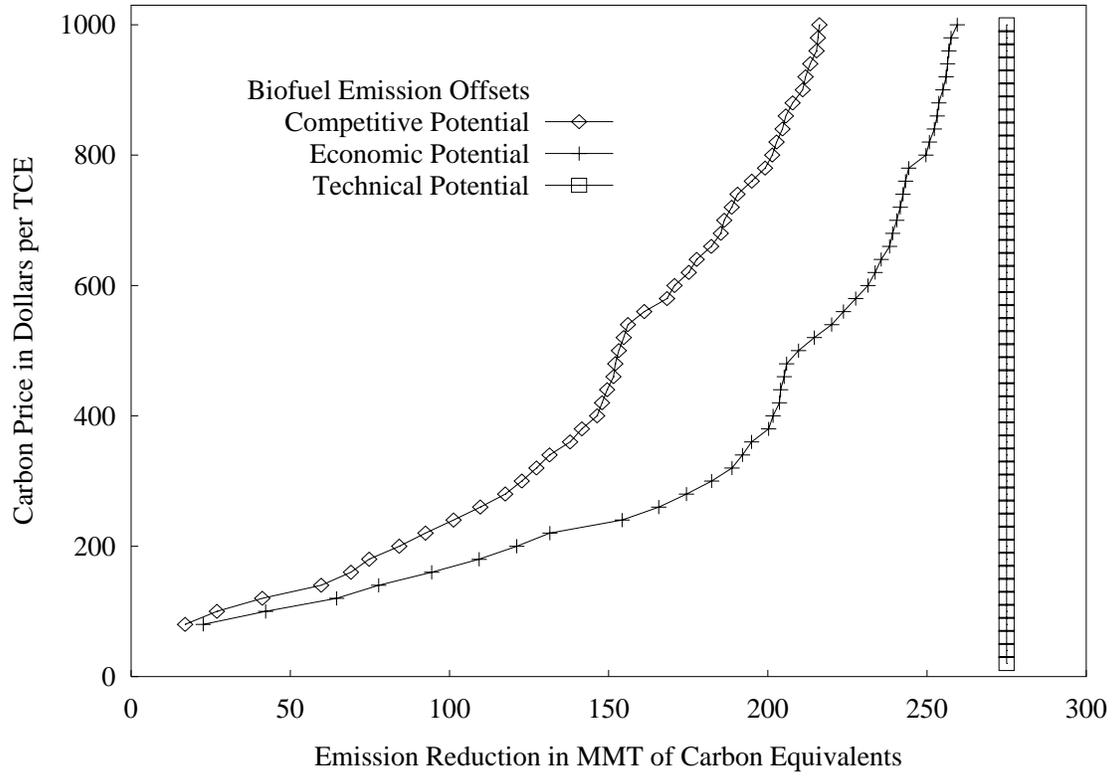
**Figure 1** Agricultural Mitigation Potential at \$0 to \$500 per Ton Carbon Equivalent Prices



**Figure 2** Agricultural Soil Carbon, Technical, Sole Source Economic and Competitive Economic Response



**Figure 3 Afforestation Carbon Sink, Technical, Sole Source Economic and Competitive Economic Response**



**Figure 4 Carbon Offsets from Energy Crops, Technical, Sole Source Economic and Competitive Economic Response**

**Table 1      Estimate of Global Potential Contribution to Change in Carbon  
Stocks by source in Million Metric Tons Carbon per year**

Source	IPCC 2000 Global Estimate	U.S. Estimate
Cropland Management	125	75-208 (Lal et al.)
Grazing Land Management	240	29.5-110 (Follett et al.)
Forest Management	170	300 (Birdsey) <sup>a</sup>
Agroforestry	26	
Afforestation	390	
Cropland to Grassland	38	6-14 (Lal et al.)
Wetland Restoration	4	
Degraded Land Restoration	3	11-25 (Lal et al.)

**Table 2 Mitigation Strategies Included in the Analysis**

Strategy	Basic Nature	Greenhouse Gas Effect		
		CO2	CH4	N2O
Afforestation / Timberland Management	Sequestration	X		
Biofuel Production	Offset	X	X	X
Crop Mix Alteration	Emission, Sequestration	X		X
Crop Fertilization Alteration	Emission, Sequestration	X		X
Crop Input Alteration	Emission	X		X
Crop Tillage Alteration	Emission	X		X
Grassland Conversion	Sequestration	X		
Irrigated /Dry land Conversion	Emission	X		X
Livestock Management	Emission		X	
Livestock Herd Size Alteration	Emission		X	X
Livestock Production System Substitution	Emission		X	X
Manure Management	Emission		X	
Rice Acreage	Emission		X	

**Table 3 Results at Selected Carbon Price Scenarios**

Category	Unit	Carbon Equivalent price in \$/metric ton C					
		10	20	50	100	200	500
Sub-Category							
<b>Strategy</b>							
Soil Carbon	1000 TCE	52,771	63,148	60,341	51,060	44,967	44,163
Afforestation	1000 TCE	13,445	20,619	116,361	183,191	192,893	192,947
Biomass	1000 TCE	0	0	26,154	61,020	105,045	113,456
Fossil Fuel Ag-Inputs	1000 TCE	4,285	6,696	10,156	12,433	14,971	15,807
Livestock Related	1000 TCE	5,674	7,390	12,462	13,989	16,547	19,443
Crop Non-Carbon	1000 TCE	1,959	2,427	5,304	9,081	12,239	13,003
<b>GHGE Mitigation</b>							
C	MMTC	71.26	91.81	216.14	309.3	356.7	364.61
CH4	MMTCH4	0.78	1.02	1.89	2.39	3.07	3.50
N2O	MMTN2O	0.04	0.05	0.09	0.14	0.18	0.20
CE	MMTCE	79.11	101.98	235.31	334.11	389.09	400.94
<b>Market Effects</b>							
Production	Fisher Index	99.81	98.74	91.20	77.77	67.73	65.37
Prices	Fisher Index	100.65	102.41	118.81	155.93	222.07	261.01
Ag-Sector Welfare	Billion \$	-0.45	-0.90	-5.65	-15.33	-29.79	-35.05
Net Exports	Fisher Index	99.17	96.11	74.26	35.33	25.58	22.81

**Other Externalities**

Nitrogen pollution	% Change	2.10	3.63	-6.26	-21.47	-34.65	-37.40
Phosphorous pollution	% Change	-43.35	-49.02	-52.93	-53.61	-58.15	-60.54
Erosion	% Change	-35.04	-41.28	-49.70	-55.62	-61.23	-63.27

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a This estimate arose from the U.S. Cop 6 negotiating position for annual sequestration by forests under Business as Usual without additional incentives(UNFCCC,2000).

## References

- Adams, D.M., R.J. Alig, J.M. Callaway, and B.A. McCarl., *The Forest and Agricultural Sector Optimization Model (FASOM): Model Structure and Policy Applications*, USDA Forest Service Report PNW-RP-495, 1996.
- Alig, R.J., D.M.Adams and B.A.McCarl. "Impacts of Incorporating Land Exchanges Between Forestry and Agriculture in Sector Models", *Journal of Agricultural and Applied Economics*, 30(2), 389-401, 1998.
- Alston, J.M. and B.M. Hurd. " Some Neglected Social Costs of Government Spending in Farm Programs." *American Journal of Agricultural Economics*, 72(1990):149-156.
- Babcock, B.A. and G.R. Pautsch. "Relative Efficiency of Sequestering Carbon in Agricultural Soils Through Second Best Instruments." Paper presented at the Third Toulouse Conference on Environment and Resource Economics - Environment, Energy Uses and Climate Change, Toulouse, France, 14-16 June 1999.
- Bennett, J.F. "Commentary on Marland, G., B.A. McCarl, and U.A. Schneider, Soil carbon: Policy and Economics." in *Carbon Sequestration in Soils: Science, Monitoring, and Beyond*. Proceedings of the St. Michaelis Workshop. edited by N.J. Rosenberg, R.C. Izaurralde, and E.L. Malone, pp. 168-170, St. Michaels, MD, December 3-5,1998.
- Birdsey, R.. 2000. Personal communication regarding work behind United States Submission on Land-Use, Land-Use Change and Forestry., see UNFCCC, 2000.

- Brown, S.J. *Opportunities for Mitigating Carbon Emissions through Forestry Activities*, Prepared for the World Bank, Winrock International, March 1999.
- Brown, S., J. Sathaye, M. Cannell, and P. Kauppi. 1996. "Management of forests for mitigation of greenhouse gas emissions". In R. T. Watson, M.C. Zinyowera, and R.H. Moss (eds.), *Climate Change 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-Technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change*, Cambridge University Press, Cambridge and New York, Chapter 24.
- Chang, C.C., B.A. McCarl, J.W. Mjelde and J.W. Richardson. "Sectoral Implications of Farm Program Modifications." *American Journal of Agricultural Economics*. 74(1992):38-49.
- Food and Agriculture Organization of the United Nations (FAO). "*State of the World's Forests 1997*." (FAO, Rome, 1997), p.16
- Follett, R.F., J.M. Kimble and R. Lal. (eds) 2001. *The Potential of U.S. Grazing Lands to Sequester Carbon and Mitigate the Greenhouse Effect*. Lewis Publishers, MI.
- Intergovernmental Panel on Climate Change, 1996. *Climate Change 1995: The IPCC Second Assessment Report, Volume 2: Scientific-Technical Analyses of Impacts, Adaptations, and Mitigation of Climate Change*, Watson, R.T., M.C. Zinyowera, and R.H. Moss (eds.). Cambridge University Press: Cambridge and New York, 1996.
- Intergovernmental Panel on Climate Change 1990: *Climate Change: The IPCC Scientific Assessment*. Cambridge University Press: Cambridge and New York, 1991.

Intergovernmental Panel on Climate Change, *Land Use, Land-use Change, and Forestry*;

Intergovernmental Panel on Climate Change, Cambridge University Press:

Cambridge and New York, 2000.

Intergovernmental Panel on Climate Change, *IPCC Third Assessment Report:*

*Contributions of IPCC Working Groups: Summaries for Policymakers*;

<http://www.ipcc.ch/> 2001

Kline D., T. Hargrove and C. Vanderlan. *The Treatment of Biomass Fuels in Carbon*

*Emissions Trading Systems*. Prepared for the Center for Clean Air Policy's

Greenhouse Gas Emissions Trading Braintrust, [Online]. Available HTTP:

[www.ccap.org/m-pub-d.htm#AIRLIEPUB](http://www.ccap.org/m-pub-d.htm#AIRLIEPUB). Washington, March 1998.

Lal, R., J. M. Kimble, R. F. Follett, and C. V. Cole. *The Potential of U.S. Cropland*

*to Sequester Carbon and Mitigate the Greenhouse Effect*, 128 pp., Sleeping Bear

Press Inc., Chelsea MI, 1998.

Marland, G. and B. Schlamadinger. "Forests for Carbon Sequestration or Fossil Fuel

Substitution A Sensitivity Analysis." *Biomass and Bioenergy* 13(1997):389-397.

Marland, G., B.A. McCarl, and U.A. Schneider. "Soil carbon: Policy and Economics."

in *Carbon Sequestration in Soils: Science, Monitoring, and Beyond*. Proceedings

of the St. Michaelis Workshop. edited by N.J. Rosenberg, R.C. Izaurralde, and

E.L. Malone, pp. 151-167, St. Michaels, MD, December 3-5, 1998.

McCarl, B.A. "Carbon Sequestration via Tree Planting on Agricultural Lands: An

Economic Study of Costs and Policy Design Alternatives." Paper presented at the

Energy Modeling Forum, Snowmass CO, 3-11 August 1998.

- McCarl, B.A. and U.Schneider. "Curbing Greenhouse Gases: Agriculture's Role".  
*Choices*, First Quarter, 9-12, 1999.
- McCarl, B.A. and U. Schneider, 2000. Agriculture's Role in a Greenhouse Gas Emission Mitigation World: An Economic Perspective. *Review of Agricultural Economics* 22:134-159.
- McCarl, B.A. and U. Schneider, "Harvesting Gasses from the Greenhouse: Economic Explorations Regarding the Role of Agriculture and Forestry" Unpublished Paper, Department of Agricultural Economics, Texas A&M University, College Station, TX, 2001.
- McCarl, B. A., D. M. Adams, R. J. Alig and J.T. Chmelik, "Analysis of Biomass Fueled Electrical Powerplants: Implications in the Agricultural & Forestry Sectors", *Annals of Operations Research*, 94, 37-55, 2000a.
- McCarl, B.A., C.C. Chang, J.D. Atwood, W.I. Nayda; *Documentation of ASM: The U.S. Agricultural Sector Model*, <http://agecon.tamu.edu/faculty/mccarl/asm.html>, 2000b.
- North, G. "Climate Change Over the Next Century", this volume, 2001.
- Paustian, K., B. Babcock, C. Kling , J. Hatfield, R. Lal , B.A. McCarl, S. McLaughlin, W. M. Post , A. Mosier , C. Rice, G.P. Robertson , N.J. Rosenberg , C. Rosenzweig, W.H. Schlesinger and D. Zilberman , "Agricultural Mitigation of Greenhouse Gases: Science and Policy Options", *Proceedings of DOE First National Conference on Carbon Sequestration*, Washington D.C., 2001
- Schlesinger, W. "The Carbon Cycle: Human Perturbations and Potential Management Options", this volume, 2001.

- Schneider, U. *Agricultural Sector Analysis on Greenhouse Gas Emission Mitigation in the U.S.*, PhD Dissertation, Department of Agricultural Economics, Texas A&M University, December 2000.
- Stavins, R.N., "Transaction Costs and Tradable Permits", *Journal of Environmental Economics and Management* 29:133-148, 1995.
- Stavins, R.N., "What Have We Learned from the Grand Policy Experiment: Lessons from SO<sub>2</sub> Allowance Trading", *Journal of Economic Perspectives* 12(3):69-88, 1998.
- Stavins, R.N. "Experience with Market-Based Environmental Policy Instruments." in *Handbook of Environmental Economics*, eds. Karl-Göran Mäler and Jeffrey Vincent. Amsterdam: Elsevier Science, forthcoming 2000.
- UNFCCC. 2000. United States Submission on Land-Use, Land-Use Change and Forestry. Pp. 84-144, In: *United Nations Framework Convention on Climate Change, Subsidiary Body for Scientific and Technological Advice. Methodological Issues: Land-Use, Land-Use Change and Forestry, Submissions from Parties.* FCCC/SBSTA/2000/MISC.6/Add.1, Sep. 2000.
- USEPA. 2000. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1998.* Office of Atmospheric Programs (6201J). Environmental Protection Agency 236-R-00-001.
- Weyant, John P., and Jennifer Hill. "Introduction and Overview," in *The Costs of the Kyoto Protocol: A Multi-Model Evaluation*, special issue of *The Energy Journal*, John Weyant (ed.). 1999.

Woodward R.T. and R.A. Kaiser. 2000. "Market Structures for U.S. Water Quality Trading" Draft Department of Agricultural Economics Texas A&M University College Station.