Economic Potential of Biomass Based Fuels for Greenhouse Gas Emission Mitigation

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Today society faces important decisions regarding climate change mitigation. Increasingly, concerns are being expressed about the potential implications of the build-up in atmospheric concentrations of greenhouse gases (GHG). A scientific consensus is emerging that this buildup will affect the global climate, most likely stimulating warming. Also, there are arguments that the disturbances caused by increased GHG concentrations will take a long time to reverse. The International Panel on Climate Change (IPCC) argues that it will take: a) centuries for the sea level to stop rising from a warming increase; b) decades for atmospheric GHG concentrations to stabilize once emissions have stabilized; and c) decades to fully retrofit and/or replace the stock of equipment, vehicles and technology which is associated with current anthropogenic emissions. Society must decide whether to let emission increases continue or reduce emissions in an effort to stabilize atmospheric concentrations. Moves in either direction face the uncertain future effects of GHG induced climate change, which have varying implications for many sectors of the economy (Mendelsohn and Newman, U.S. Global Change Research Program National Climate Change Assessment). In essence the decision involves whether to insure against possible future deleterious effects by either directly reducing emissions or indirectly by creating sinks, which offset emissions.

Agriculture can potentially play a role in an effort to reduce net emissions of greenhouse gases. While agriculture is a small emitter of the most prevalent greenhouse gas (carbon dioxide - CO_2), it is important in the total picture. According to the latest United States EPA inventory, anthropogenic GHG emissions from agriculture contribute 7% of total carbon equivalent emissions releasing about 28% of methane emissions and almost 70% of nitrous oxide. Furthermore, agriculture has substantial potential for offsetting emissions by serving as a sink augmenting the GHG absorption, particularly CO_2, through changes in tillage or land use including conversion of cropland to grassland

or forest. Agriculture can also offset GHG emissions by increasing production of biomass commodities, which can serve either as feedstock for electricity generating power plants or as blend/substitute for fossil fuel based gasoline. Biofuels mitigate GHG emissions because their usage spares fossil fuel use. The net emission savings from biomass amount to approximately 95 percent of the emissions from extraction and combustion of an equivalent amount of fossil fuels (Kline, Hargrove and Vanderlan; Mann and Spath).

The production of biofuel feedstocks from agricultural and forestry sources has been considered for many years, particularly just after the 1970's "energy crisis". However, in the U.S. biofuel production has not proven to be broadly economically feasible without subsidies (current U.S. ethanol subsidies amount to over 50% of product sale price) nor is it likely to be in the near future. There are four possible justifications for subsidization of biofuels. First, biofuel subsidies serve to support agricultural prices by adding to demand for feedstock commodities and in turn supporting agricultural incomes. Second, the biofuel product ethanol has desirable environmental/health attributes relative to petroleum-based fuels, which play a role in meeting clean air standards. Third, such subsidies reduce dependence on petroleum extending the life of existing stocks and possibly reducing reliance on foreign supplies. Fourth and as mentioned above biofuel combustion substantially offsets net GHG emissions relative to fossil fuel combustion.

In this paper, we examine the first and fourth motivations for biofuel feedstock production in a U.S. setting. We analyze the role biofuels might play in total greenhouse mitigation policy and the implications for the agricultural sector. Biofuels are measured in terms of their net contribution to GHG emissions in terms of CO_2, nitrous oxide and methane. We also consider biofuels not independently but rather in comparison with a total suite of agricultural mitigation options. Such a comparison allows us to examine the relative desirability of biofuels vis a vis other GHG mitigation strategies such as tillage

alteration, tree planting, fertilization alteration, livestock dietary alteration and manure management.

Background: Agriculture's Role in Total Greenhouse Gas Mitigation Strategy

Agriculture can participate in GHG emission mitigation efforts as an emission reducer, sink, or offsetter. In this study we consider all of these roles simultaneously. Thus it is beneficial to devote coverage to the potential ways agriculture can participate in GHG emissions (we briefly summarize such roles but for more comprehensive treatment see the 1999 and 2000 papers by McCarl and Schneider).

In the context of agriculture as an emitter, there are a number of management alternatives which can influence net agricultural contribution to the total emissions program. In particular, a) methane emissions are affected by the size of the livestock population, the use of livestock rearing practices which influence enteric fermentation (diet and growth rate stimulation) and manure management; b) nitrous oxide emissions are influenced by fertilization quantity or practices (through increased soil testing, use of denitrification inhibitors or increased manure substitution), c) rice acreage can be reduced to lower methane emissions and d) energy intensity of agricultural practices can be reduced to lower fossil fuel based emissions from production as well as input manufacture and product/input distribution (EPA,1999a,b).

Agricultural GHG sinks can be expanded through increase of: a) the proportion of cropped acres tilled by less intensive methods relative to the acres tilled by conventional deep plowing (Rosenberg, Izaurralde, and Malone; Marland, McCarl, and Schneider(2000), Cole et al.), b) the acreage transformed from cropping usage to grasslands or forests (Sedjo, McCarl), or c) the carbon holding capacity of degraded crop, pasture or abandoned lands by altering vegetative cover use or by improving management (Lal et al., Cole et al.).

Finally, in the context of agriculture as an offsetter one can: a) use biofuel based strategies as discussed above or b) otherwise produce agricultural commodities which through their consumption substantially offset emission intensive non-agricultural commodities (Marland and Schlamadinger). For example, wood from forests may be substituted for steel or concrete in building construction.

Given the wide range of possible agricultural reactions to GHG mitigation policy, the question becomes: Which strategies are feasible from a combined political, technical and economic viewpoint? From here on we will investigate this question from an economic viewpoint.

Issues in Appraising Economics of Agricultural Emission Reductions

Emission reductions via agriculture raise several important issues concerning the economic analysis framework. These include multiple gas tradeoffs, use of sectoral level analysis, incorporation of detailed farm level GHG emissions and biofuel feedstock production possibilities.

Multiple Gas Tradeoffs

Agricultural production contributes to emissions of multiple GHGs. For example, a crop-livestock farm releases CO_2 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.

In this study, the IPCC's global warming potential (GWP) concept was used to construct an aggregate measure of changes in the level of agricultural emissions. The GWP compares the radiative forcing of the various GHGs relative to CO_2 over a given time period (Cole et al.). The 100-year GWP for CO_2 equals 1. Higher values for methane (21) and nitrous oxide (310) reflect a greater heat trapping ability. We formed a

ton of "carbon equivalent" measure also factoring in an adjustment for the molecular weight of carbon in CO_2.

Need for Sector Analysis

To assess how agriculture might respond to incentives for GHG emission mitigation, a sector-level approach is needed. This notion will be justified by placing agricultural emissions in perspective with the Kyoto Protocol.

U.S. cropland amounts to approximately 325 million acres. The literature suggests a maximum potential for agricultural carbon sinks is around one ton of carbon per acre (for example see Stavins). Using this maximum, total agricultural contribution to carbon storage may be bounded at about 300 million tons, annually. The Kyoto Protocol, however, contains a 1990 less seven percent U.S. limit (United Nations, Framework Convention on Climate Change). Using EPA emissions inventory data, this implies annual emission reductions of about 300 million tons plus emissions growth by 2010 (which by linear extrapolation would add 400 million more tons) for a total in the neighborhood of 700 million tons. Clearly, such large emission volumes could not be offset through cropping agriculture even if all available cropland were retired.

The above argument suggests that GHG emission mitigation efforts could greatly impact the agricultural sector with accompanying adjustments in production, prices, and welfare. Consequently, a sector wide analysis of agricultural mitigation options is appropriate. To pursue such an analysis we will employ a price endogenous sector model utilizing a soil type and tillage system dependent version of the Agricultural Sector Model (ASM) maintained by McCarl et al.

Incorporation of GHG Emission Mitigation Alternatives

The agricultural opportunities for emission are numerous and geographically diverse. For example, the potential of a particular region to enhance soil carbon storage depends on soil types, current tillage systems, crop rotations, and management practices. Numerical specification of a full set of net emission reduction alternatives requires a

detailed and comprehensive data set giving the implications of all of the practices for each location. Such a data set was not available but could be developed using a crop and carbon simulation model. For this analysis, we generated data through a recent version of the EPIC crop simulator (Williams et al.), can simulate yield, carbon sequestration and nitrous oxide emissions under alternative management regimes. We simulated such management across five regionally representative soil classes for 63 U.S. regions for numerous crops under a range of fertilization, tillage, and irrigation practices. The EPIC model output contained estimates of soil carbon sequestration, nitrous oxide release, and several other environmental effects (erosion, nitrogen percolation).

Biofuel Feedstock Modeling

For this study we needed to use a version of the sector model which contained a biomass feedstock component. We adapted the biomass feedstock component developed in McCarl, Adams and Alig. Therein production possibilities include growing biomass crops of willow, switchgrass, or poplar for power plants as well as the diversion of a conventional crop (corn) for ethanol production. We specified the willow, switchgrass, or poplar production technologies using data from the Oakridge National Laboratory (Walsh et al.). The ethanol from cornstarch technology was based on data from Coble et al. and Shapouri.

Net emission savings from biofuel production represent savings over net emissions from conventional fuels. Complete lifetime cycle assessments of conventional and alternative energy sources (Spath and Mann; Wang, Saricks, and Santini) provided necessary emission coefficients for this calculation. In addition to CO_2 offsets, the model also incorporates the effects of biofuel alternatives on methane and nitrous oxide emissions.

Modeling Background

The study being done here starts with the ASM model of McCarl and associates (Chang et al., McCarl et al.) and adds greenhouse gas mitigation possibilities. The ASM

model was first developed in the mid-1970s and has been used in many economic appraisals regarding environmental policies. Previous applications addressed tropospheric and stratospheric ozone, acid rain, coastal zone management, soil conservation policy, farm program policy, global warming, pesticide policy, GHG mitigation, and a variety of other agricultural/environmental programs (see the review in Chang et al. for references). In these appraisals ASM has been used to study the effects of long-term changes on agricultural income, production, consumption, trade, and environmental attributes.

A new version of ASM was developed for this study (ASMGHG) which contains details on GHG emission related management alternatives (see Schneider for a full description). ASMGHG projects changes in net emissions of CO_2, methane, and nitrous oxide in response to changes in agricultural management weighting the gases into carbon equivalents as discussed above. ASMGHG is designed to examine the impact on the agricultural sector of alternative levels of carbon equivalent emission prices as well as the way the choice of "optimal" mitigation strategy very since prices get.

The sector model also examines the multi-enterprise implications of particular mitigation policies. Some of the mitigation alternatives target emissions from livestock by altering the management practices which contribute to methane emissions through enteric fermentation and manure handling. Such alternatives could also indirectly effect emissions of CO_2, methane, and nitrous oxide from crops due to shifts in feed demand with accompanying alterations in the feed production, crop fertilization and choice of tillage systems. ASMGHG captures simultaneous effects across the total agricultural sector.

In terms of scope, ASMGHG is an U.S. wide agricultural sector model, which also incorporates production and trade activity in the rest of the world. It depicts production in 63 U.S. agricultural sub-regions endogenizing crop choice, irrigation choice, livestock numbers, livestock management and employment of the GHG strategies

mentioned above. Commodity coverage is broad with more than 30 commodities considered including the major U.S. feed and food grains, oilseeds, fiber, hay, silage, sweetener, cattle, sheep, poultry, dairy and hog commodities. There is also a depiction of production of eight major internationally traded commodities in 27 rest of the world regions and detailed international trade depiction for those commodities. Trade and consumption of more than 50 other commodities are modeled at a more aggregate level. Production is gathered together into ten U.S. marketing regions and in turn shipped on to processing, consumption or international markets. ASMGHG solutions provide projections of land use and commodity production within the 63 U.S. areas, commodity production in the rest of the world, international trade, crop and livestock commodity prices, processed commodity prices, agricultural commodity consumption, producer income effects, consumer welfare effects, environmental loadings, and in ASMGHG the employment of the various GHG emission strategies.

Results

To study mitigation efforts, we simulated sectoral response to a range of hypothetical carbon equivalent prices. The range was chosen to span the projections of potential carbon prices we found in the literature. For example, the U.S. President's Council of Economic Advisers has taken a position that the carbon price will be somewhere in vicinity of $20 per ton while estimates by modeling groups such as MacCracken et al. show carbon prices between $18 and $260 per ton. Based on these and other estimates we chose to vary the carbon price in $20 increments between $0 and $500 per ton with the high-end chosen in an effort to find total potential regardless of cost.

Emission Reduction Potential

Figure 1 shows total emission reductions from all incorporated agricultural mitigation options. The results indicate that net emission reductions increase up to a

maximum of about 300 million metric tons (MMT) of carbon equivalents. However, for prices in the range of $50 to $100, overall reductions remain below 120 MMT. In Figure 1, total agricultural net emission reductions are decomposed into contributions from individual GHGs. Carbon dioxide abatement strategies constitute the largest supply component. Methane abatement strategies add considerably less not exceeding 50 MMT even under high reduction incentives. Nitrous oxide emission contributions are low.

Figure 2 provides details on individual carbon dioxide mitigation options including the production of biofuels. The simultaneous inclusion of major agricultural mitigation strategies allows us to identify preferred strategies at each incentive level. At low prices the model concentrates on the usage of soil based carbon sequestration with some emission reductions arising from adoption of methane abatement options. As the price level increases above $60 per ton, switchgrass based biomass comes into production and above $100 we also encounter willow based biomass. Furthermore, for prices above $80 per ton the biofuel feedstock production strategies dominate all other agricultural GHG mitigation strategies. These observations confirm that the woody biofuels are not competitive at the current zero price for carbon. Also note cornstarch-based ethanol does not increase beyond current levels of production even if stimulated by high mitigation incentives.

Mitigation Induced Welfare Effects

ASMGHG computes welfare effects on producers, consumers, and foreign trading partners. As mitigation incentives increase, total economic surplus in the agricultural sector decreases monotonically (Figure 3). This loss provides a measure of the minimum benefits society should gain from reduced levels of GHG emissions. Only if the perceived benefits exceed financial losses, the mitigation policy can be judged potentially efficient by the Kaldor Hicks compensation test provided transaction costs of policy implementation remain feasible.

Decreasing overall economic surplus in the agricultural sector also underlines the fact that current welfare levels are in part based on emission intensive agricultural technologies and shifting to biofuel production or other mitigation alternatives is not cost free. However, the costs of using emission-abating practices are not shared equally among agricultural market segments. In particular, higher costs to producers are more than offset by higher revenues due to increased prices. Thus, as shown in Figure 3, the net effect on producers' welfare is positive. Domestic consumers' welfare, on the other hand, decreases substantially.

Effects on Production of Traditional Agricultural Products

Large-scale production of biofuels decreases the amount of land that is available for traditional agricultural products and for other land use based mitigation strategies. Figure 4 shows this competition. In turn this causes effects in agricultural product markets. A summary of the effects of increased biofuel production on traditional agricultural production is provided in Figure 5. Agricultural commodity prices are sensitive to carbon prices (Figure 5). For example, corn prices rise by 15 percent when the carbon price goes from zero to $100 per ton. Commodity prices go up because of increased competition for land and because of increased costs from emission-intensive key inputs. Changes of the aggregate agricultural price index occur at different intensities. For carbon prices between $0 and $60 per ton, average prices increase only up to 3.5 percent. Higher carbon prices, however, accelerate price changes. Particularly, between $60 and $200 per ton, average prices rise by about 5 percent for every $20 incremental increase in the price of carbon.

Note again that a $60 per ton of carbon value begins the dominance of biofuel based mitigation. Below that price the mitigation options do not markedly reduce traditional agricultural commodity supply. Strategies such as reduced tillage in cases increase traditional long-term crop yields because of the beneficial effects of increased soil organic matter on nutrient availability, water holding capacity, and physical soil

structure. Biofuel production, though, is unambiguously competitive with food production causing prices to rise faster.

Figure 5 also displays changes in acreage, yields, production, and net exports of agricultural commodities. Yields decrease slightly for low carbon prices and reach a relative nadir at $60. As biofuel production initiates, average yields on the remaining food crop acreage start going up again and reach original values at a carbon price of about $120 per ton. Total exports of traditional agricultural products decline monotonically. At a carbon price of $60 per ton, food exports decline by 5 percent relative to the base situation. Carbon incentives between $60 and $200 per ton yield a 6 percent decrease in food exports for every $20 increase.

Effects on other Environmental Indicators

Emissions of GHGs constitute just one out of many environmental externalities linked to agricultural production. For this study, we examined the effects of mitigation incentives on three additional agricultural externalities, nitrogen and phosphorous percolation, and erosion (Figure 6).

Figure 6 shows decreasing levels of nitrogen and phosphorous pollution along with reductions in soil erosion as carbon prices increase. However, most of the gains occur during the low carbon prices where mitigation does not involve biofuel production. As the biofuels begin to dominate (carbon price > $60 per ton), some of externality accounts begin to increase. For example, phosphorous losses increase slightly for carbon prices between $80 and $240 offsetting up to 10 percent of the initial 40 percent loss reduction.

Conclusions

This study examined the relative role of biofuels in a policy arena where efforts were made to reduce net GHG emissions by creating a market, which value emission reductions. Biofuels could play an important part in such a market provided the carbon

equivalent price was someone above $60 per metric ton. At prices below that level the opportunity cost of resources used in biofuel production are in excess of the value the feedstocks plus the carbon offset generated. Only the ability to collect benefits from carbon savings makes the biofuels competitive. The competitiveness of the biofuels prices above $60 arise because biofuels continually offset fossil fuel based emissions and fare well in comparison to, for example, changing tillage system use, which initially leads to increases in soil carbon but then later saturates since the soil reaches the new equilibrium. Biofuels may also yield other ancillary benefits in terms of air quality but that is not explored in this study.

Thus biofuels may face a brighter future than that portended by previous economic analyses but the big question is: Will society choose to reward their carbon recycling characteristics? This will entail society making a decision to attach a substantial price to the right to emit GHGs into the atmosphere.

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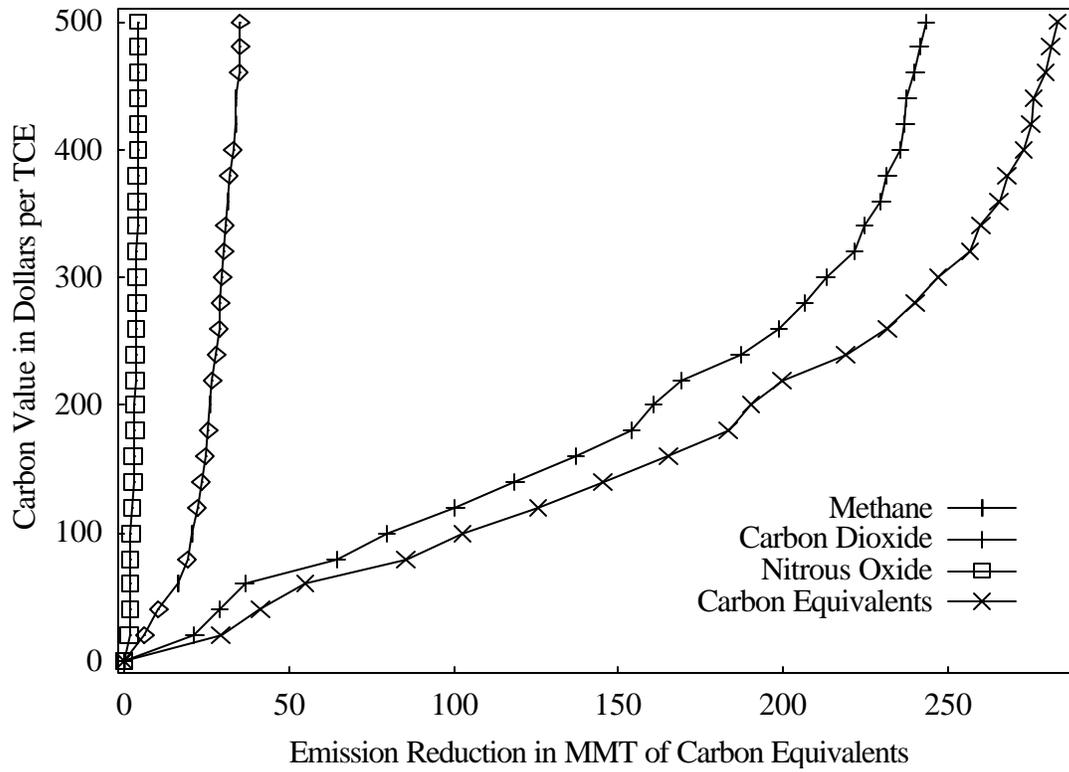
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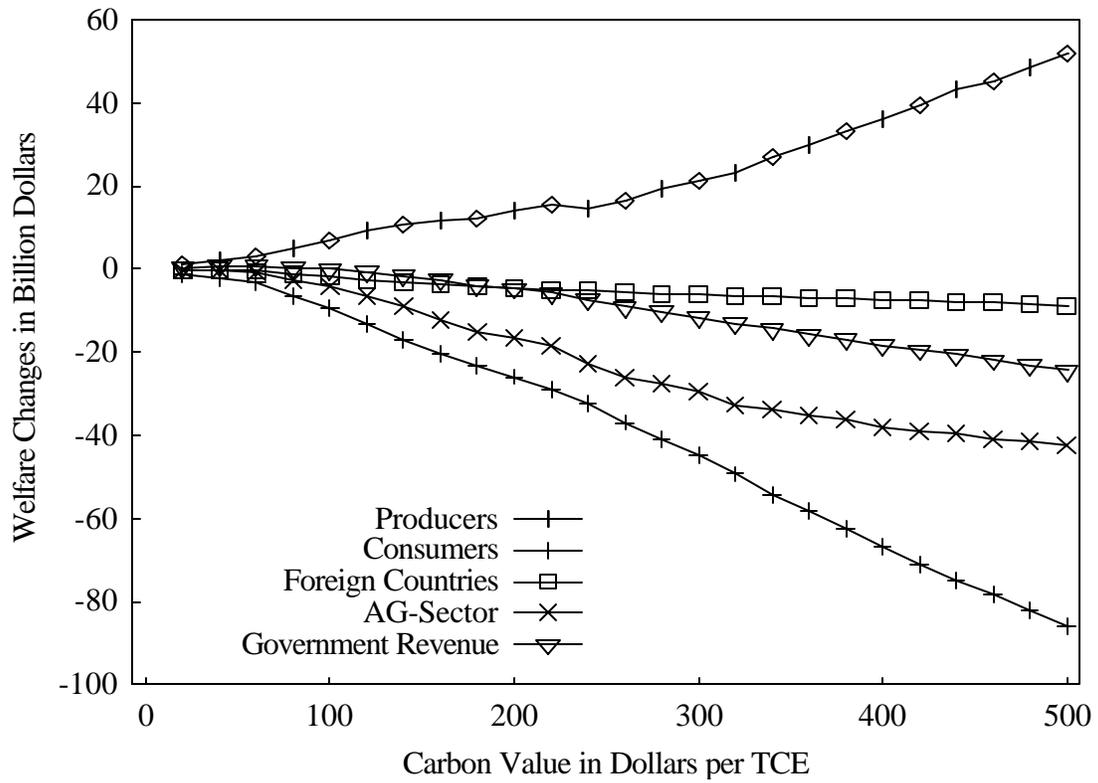
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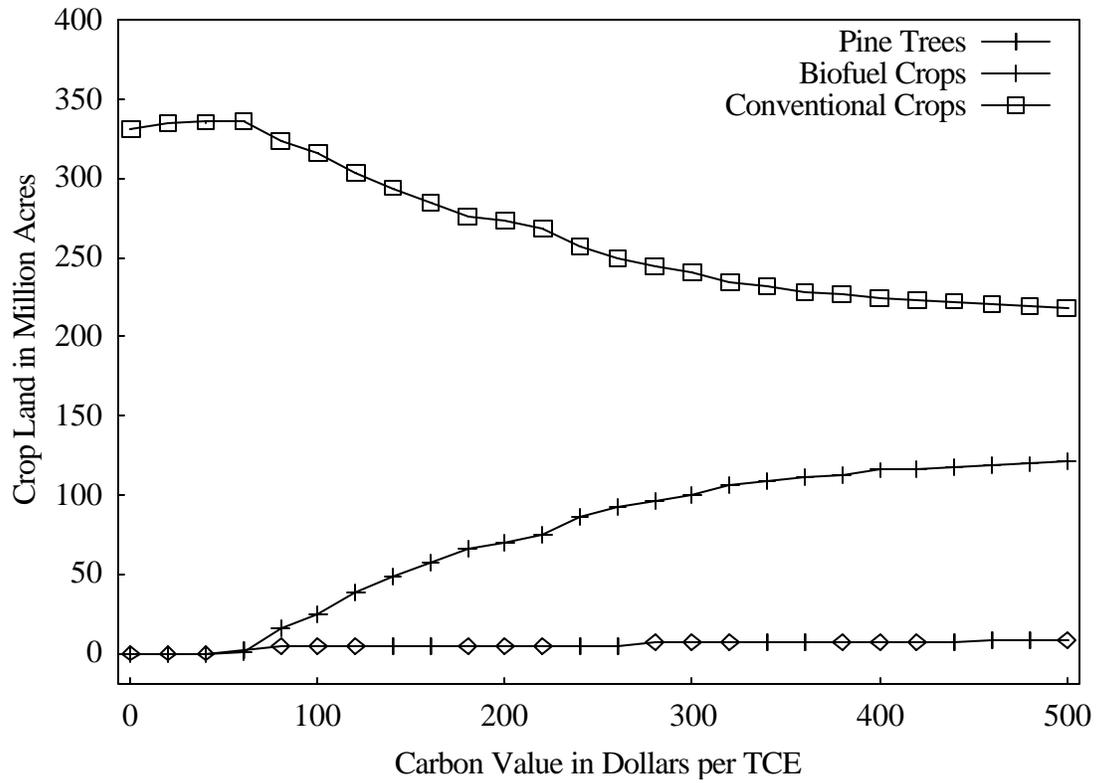
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Figure 1:   **Total Emission Reductions from the Agricultural Sector and**
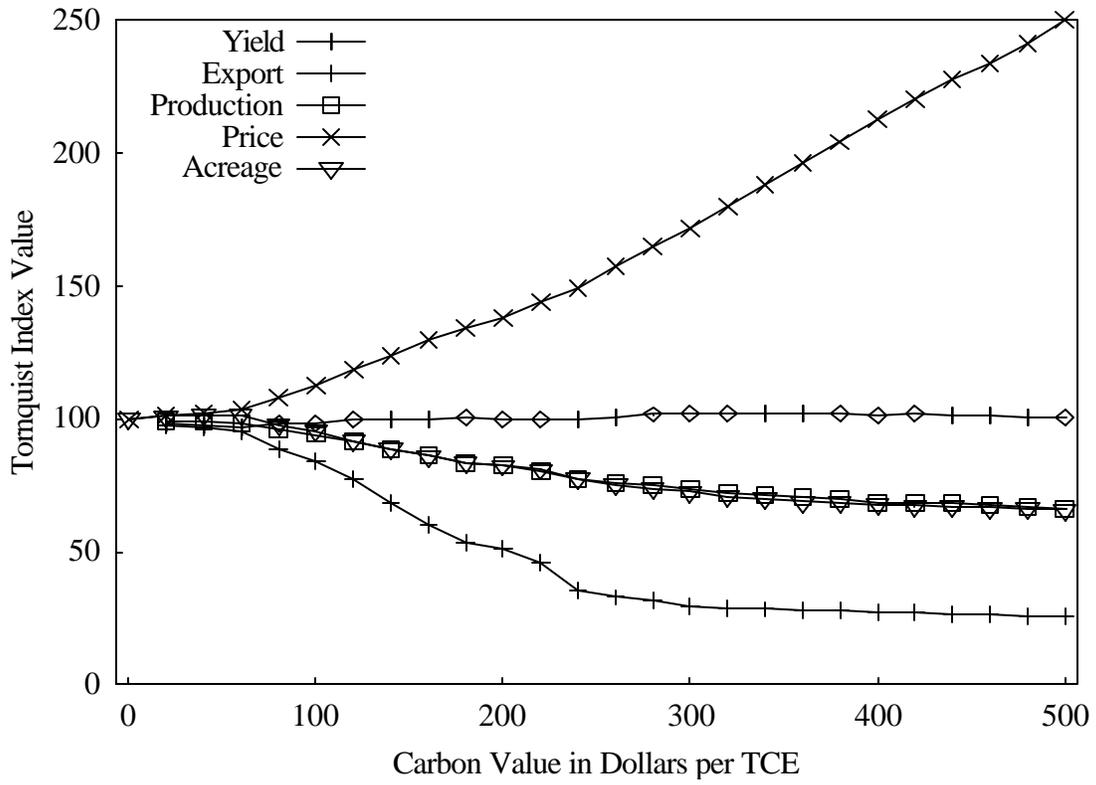
Contribution of each Greenhouse Gas
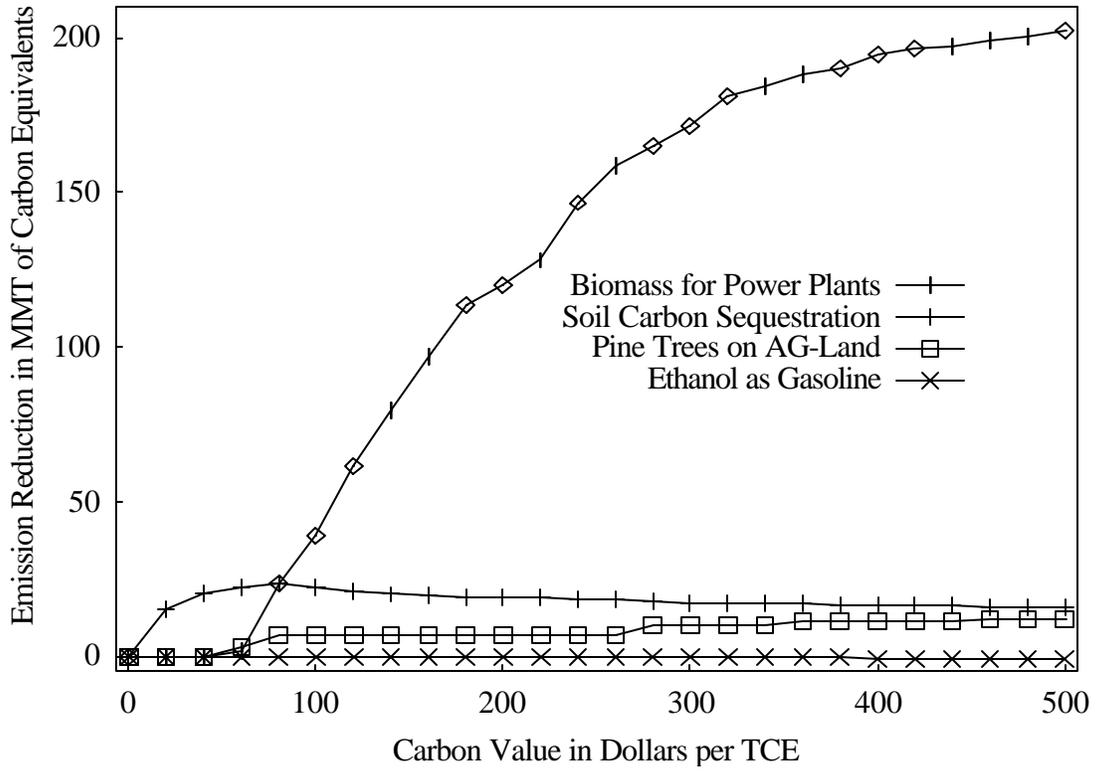
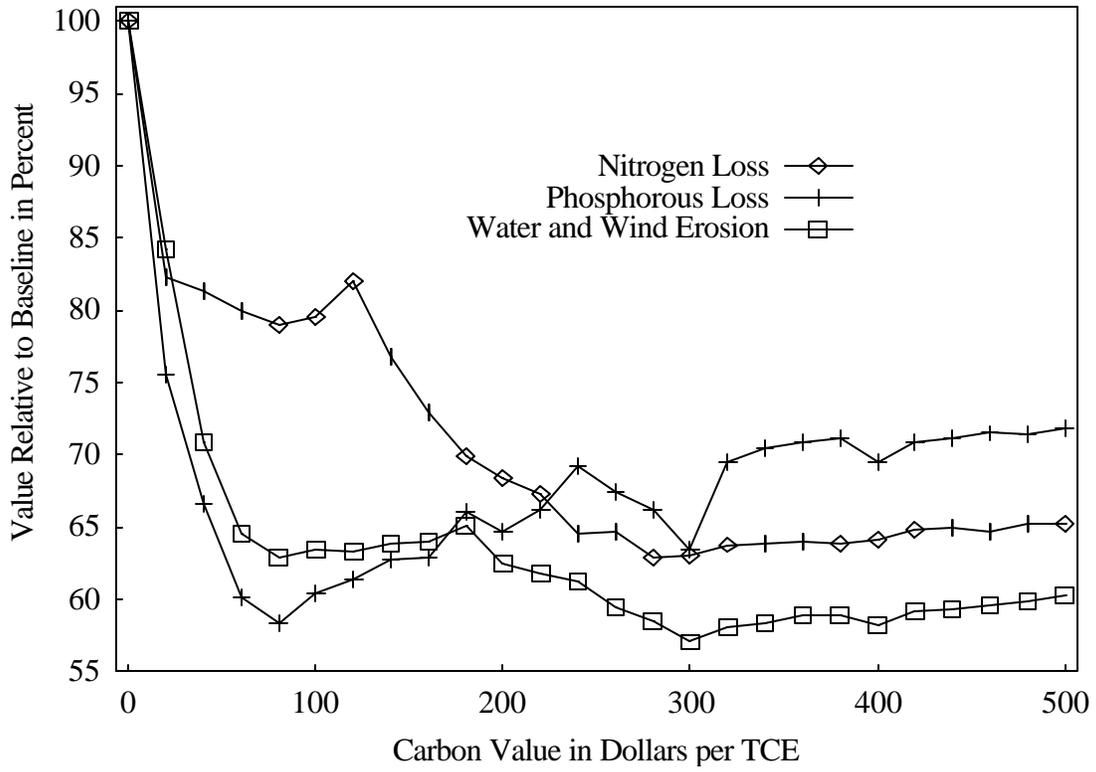**Figure 2   Total Amount of CO₂ Emissions Sequestered**

Figure 3: **Welfare Effects in the Agricultural Sector in Response to Various Carbon Prices**

Figure 4   Effects of GHGE Mitigation Incentives on Diversion of Land Use

Figure 5:   **Effects of Agricultural Mitigation Efforts on Traditional Agricultural Production**

Figure 6: **Effects of Agricultural Mitigation Efforts on Environmental Accounts**