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Trapping Greenhouse Gases: A Role for Minnesota Agriculture in Climate Change Policy

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Introduction and background

In 2009, America's role is taking shape in one of the central challenges of our times. In April, after a two-year scientific review ordered by the Supreme Court, the U.S. Environmental Protection Agency found that carbon dioxide contributes to air pollution that may endanger public health and the welfare of current and future generations. In May, legislation to establish the nation's first-ever limits on greenhouse gas emissions began moving through Congress. The massive "American Clean Energy and Security Act of 2009," or Waxman-Markey bill, would set aggressive emission reduction goals and establish a national cap-and-trade program that would dwarf existing carbon markets. The Obama Administration has consistently placed energy and climate policy at the center of its domestic and international agendas.

These developments follow activities in many American states over the past decade. A case in point is Minnesota, where an effective bipartisan effort has been under way. Minnesota has the nation's strongest renewable energy standard, requiring utilities to produce at least 25% of total energy from renewable sources by 2025. In 2007, legislation established aggressive emission reduction targets and time tables. This was followed by a Governor-led initiative to involve a wide cross-section of stakeholders in advising the government on how to reach targets. The Minnesota Climate Change Advisory Group developed 46 recommendations across all economic sectors. Gov. Tim Pawlenty also helped launch the Midwest Governors Greenhouse Gas Accord, an agreement among 11 member and observer states and Canadian provinces to cooperate in region-wide energy efficiency, bio-economy, cap-and-trade, and other programs. In mid-2009, the group's proposals — reflecting a Midwestern perspective on energy and climate issues — are being forwarded to Washington and state capitols for action.

In all the activities cited, there is unanimity on one point: broad and sustained participation across society will be needed to reduce GHG emissions sufficiently to slow global warming. Although energy efficiency, fuel efficiency, and reducing carbon intensity in energy and industrial sectors are the principal focus of development and regulatory activity, there is an appreciation for the role land use and related products can play, particularly in rural states with large resource bases in forestry and agriculture.

Terrestrial carbon sequestration — natural absorption and storage of carbon dioxide (CO_2) in plant tissue — and protection, expansion, and enhancement of carbon stocks on the land is the focus of this paper. It summarizes research, analysis, and recommendations of the Minnesota Terrestrial Carbon Sequestration Initiative, an effort based at the University of Minnesota to develop information and foster a public dialogue about carbon sequestration options in the state. Since its inception in 2005, its advisory group of government and stakeholder representatives has tasked researchers to produce scientific, economic, and policy information to increase public understanding and guide state policy. In 2007, the Minnesota legislature funded a comprehensive assessment of the potential capacity for carbon sequestration in Minnesota's terrestrial ecosystems, including an inventory of Minnesota lands having high carbon stocks; a quantification of the ability of various land use practices to sequester carbon; identification of monitoring sites and demonstration projects; and an analysis of state policies affecting terrestrial carbon stocks. Part I of the paper summarizes key findings and conclusions of those assessments. Part II describes alternative approaches to financing the broad deployment of terrestrial carbon sequestration activities. Traditional conservation programs on public and private lands and opportunities presented by the emerging carbon market auctions and offsets are also described.

Part I: Assessing terrestrial carbon sequestration in Minnesota

The global carbon cycle is one of the fundamental natural processes that define and support life on earth. Carbon flows through four major pools: the atmosphere, oceans, land (terrestrial biosphere), and the earth's interior. Carbon is one of the primary constituents of living things, comprising roughly 40% of the dry weight of biomass. In addition, the carbon cycle plays a key role in moderating the earth's climate system, using CO_2 in the atmosphere to trap solar radiation needed to warm the earth.

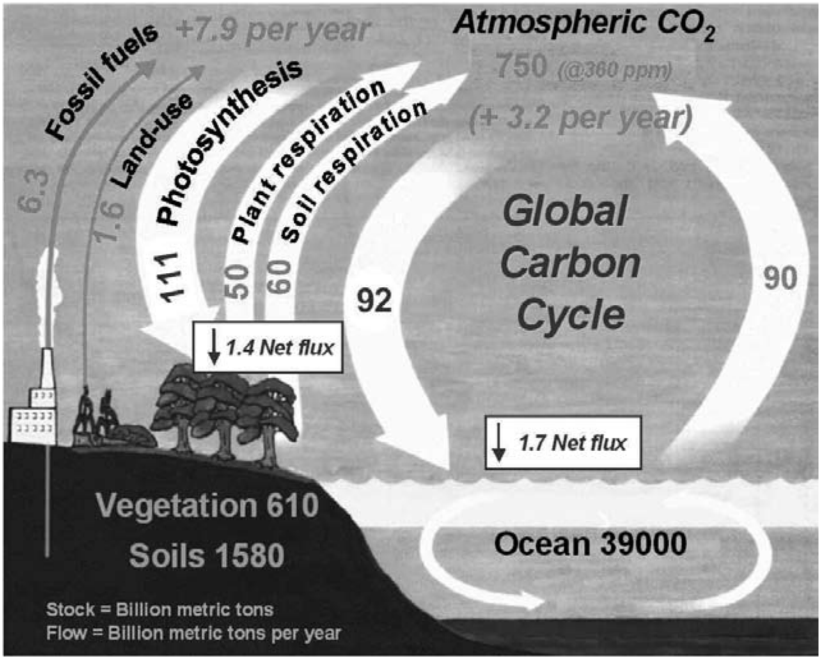

Figure 1: *Gloal carbon cycle.*

Source: University of Michigan, http://www.globalchange.umich.edu/. ../carbon_ cycle.jpg

In the past several hundred years, human activities — principally the burning of fossil fuels and deforestation — have greatly accelerated flows of carbon as CO_2 out of the land and the earth's interior and into the atmosphere. Fossil fuel (coal, oil, and natural gas) combustion releases carbon that has been locked in the earth for millions of years and has raised atmospheric CO_2 concentrations 35% higher than at the beginning of the industrial era. Overwhelming scientific evidence has confirmed that excessive buildup of atmospheric CO_2 is warming the earth to unprecedented levels and setting in motion long-term (century to millennial) changes in the earth's climate. Although once thought to be a problem that would evolve slowly, more rapid shifts in weather patterns are now observed around the world (IPCC, 2007).

Carbon flows between land and atmosphere occur through photosynthesis, when green plants absorb sunlight and take up carbon dioxide from the atmosphere, and through plant respiration and decomposition, when carbon dioxide is returned to the atmosphere. The seasonal uptake and release of carbon dioxide

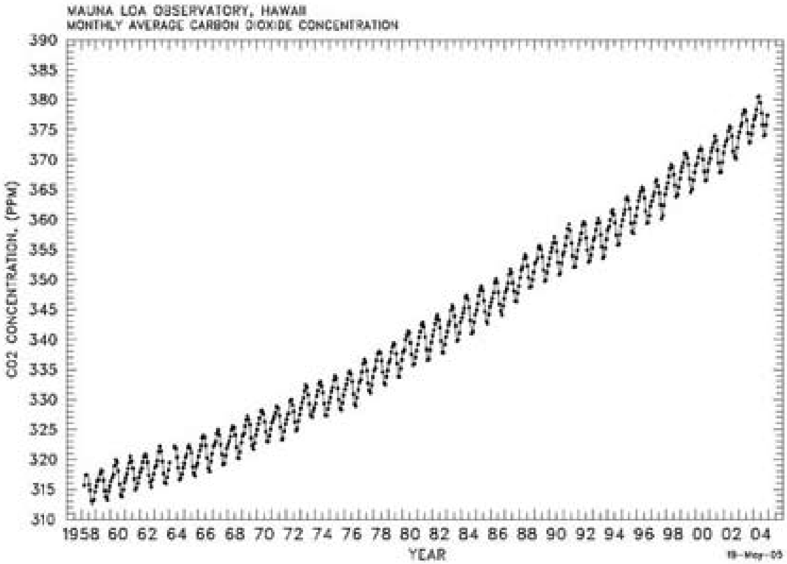

Figure 2: *Mauna Loa Curve.*

Source: http://www.globalchange.umich.edu/globalchange1/current/labs/Lab12_VirtualEarthquake/Carbon_files/image004.jpg

by northern hemisphere vegetation is graphically portrayed by the Mauna Loa Curve, a jagged upward-trending line tracking atmospheric CO_2 concentrations at a federal observatory in Hawaii beginning in the 1950s. This now-famous curve documented for the first time the rapid rise in carbon dioxide in the earth's atmosphere (Keeling, 1976).

Terrestrial carbon sequestration[1] occurs when the quantity of carbon in terrestrial carbon pools increases over time. Increases in the size of the terrestrial carbon pool occur at the expense of the atmospheric CO_2 pool, thus leading to a decrease in the quantity of greenhouse gases in the atmosphere, or at least a decrease in the rate of increase of atmospheric CO_2 concentrations. Organic carbon is a concentrated form of carbon dioxide: 3.67 tons of carbon dioxide are condensed into a single ton of organic carbon. Carbon can be stored for hundreds of years in trees or thousands of years in soils.

Different land cover types store varying amounts of carbon, with higher amounts in forests and perennial plants. Numerous other factors affect the ability of ecosystems to store carbon — age and condition of vegetation, temperature and precipitation, landscape, and land use history all play a part, as do human activities. The conversion of natural vegetation to arable or urban land results in releases of stored carbon; reforestation and re-vegetation re-start the slow sequestration process. Except for wetland drainage, large-scale land conversion in the northern hemisphere has largely abated and in New England, extensive forests have been re-established. This is not the case in the southern hemisphere, where tropical deforestation accounts for roughly 20% of human-generated GHG emissions each year. At present, the global land mass is believed to function as a small net sink (more CO_2 in-flow than out-flow), although concern is increasing about wildfire and other impacts of climate change that may reduce the ability of ecosystems to sequester carbon.

A major part of Minnesota's carbon pool resides in millions of acres of forests and peatlands (bogs, marshes, fens, and other wetlands). Peatlands contain, on average, 750 metric tons of carbon (or 2,752 $mtCO_2$) per acre. Across the state, peatlands are estimated to sequester over 15 billion tons of CO_2, or over twice the annual total GHG emissions of the United States. On an acre-by-acre basis, forests average about 100 metric tons of carbon (or 367 $mtCO_2$), or about one eighth as much carbon as peatland, but are much more susceptible to loss by fire, invasive pests and disease, and land use conversion. Between 1976 and 2008, Minnesota fires destroyed an average of 14,600 acres of forest per year (MDNR, 2008); Minnesota's no-net-loss laws have reduced net wetland loss to approximately 450 acres a year (MBWSR, 2005).

Changes in land use, land cover, and land management can alter the rate of carbon sequestration by enhancing CO_2 uptake by plants and/or by slowing its decomposition and the return of CO_2 to the atmosphere. Conversion of annual crops to perennial grasses or forest slows the return of carbon to the atmosphere because biomass is not harvested and relatively more carbon is transferred to the soil. Converting annual cropland and areas of depleted soils to deep-rooted perennials or woody species essentially increases the carbon capacity or density per unit of land area.

How much additional carbon can a particular management practice sequester? For some purposes, simply knowing if land use or management changes tend to increase or decrease carbon stocks is sufficient. For other purposes, such as determining the potential sequestration (and GHG mitigation) capacity of Minnesota's forest and agricultural land, it is necessary to quantify carbon sequestration rates and capacities of different land cover types, and then multiply by the land area involved.

The table below presents quantified estimates of thirteen different land use, land cover, and management changes prevalent

Table 1: *Estimated changes in C sequestration rates upon land use or cover change for the state of Minnesota. Estimates are means of all studies with standard deviations (SD) among studies within a land use/land cover change category, except where noted.*

Sector		Land use/ cover change	Estimated C and CO_2 sequestration rate upon land use/cover change^					
			Total biomass	Soil	Sum	Level of Certainty		
			metric ton C $acre^{-1}$ yr^{1} ± SD (n) (90% confidence interval)			of the mean rate£	that C sequestration > 0	metric ton CO_2 $acre^{-1}$ yr^{1} ± S.D.*
Wetland	a	Peatland restoration	0.2 ± 0.1 (5) (0.1 – 0.2)		0.2 ± 0.1	Medium	Very high	0.7 ± 0.4
	b	Prairie pothole restoration	N.A.	1.2 ± 1.9 (27)$ (0.6 – 1.9)	1.2 ± 1.9	Low	Very high	4.5 ± 6.9
Forestry	c	Annual row crop to forests	1.3 ± 0.5 (11) (1.1 – 1.6)	0.2 ± 0.1 (7) (0.1 – 0.2)	1.4 ± 0.5	High	Very high	5.5 ± 1.8
	d	Annual row crop to short-rotation woody crops	1.5 ± 0.6 (5) (0.9 – 2.1)	0.4 ± 0.4 (2) (-1.2 – 2.0)	1.9 ± 0.7	High	Very high	7.0 ± 2.6
	e	Increased forest stocking	0.2 ± 0.3 (29)$ (0.2 – 0.3)		0.2 ± 0.3	Low	High	0.8 ± 1.0
Agriculture	f	Annual row crops to pasture/hay land		0.1 ± 0 (3) (0.1 – 0.2)		High	High	0.4 ± 0.1
	g	Annual row crop to perennial grassland		0.4 ± 0.4 (24) (0.3 – 0.6)		Low	High	1.6 ± 1.6
	h	Conventional to conservation tillage		0.1 ± 0.1 (16) (0 – 0.1)		Low	Very low	0.3± 0.5
	i	Inclusion of cover crops in row crop rotation		0.2 ± 0.1 (4) (0.1 – 0.3)		Medium	High	0.6 ± 0.3
Perennial Grassland	j	Low diversity to high diversity grassland		0.1 ± 0.4 (4) (-0.4 – 0.5)		Low	Very low	0.1 ± 1.39
Urban	k	Turfgrass to urban woodland	0.24 ± N.A. (1)			Low	Very high	0.9 ± N.A.

in the state, denominated in metric tons of CO_2 per acre per year ($mtCO_2$/ac/yr). For policy purposes, this is also shown in megatons per year (million metric tons, or Mt/yr). Annual carbon sequestration rates are based on averages from empirical studies in areas with climates and soils similar to Minnesota. In interpreting the chart, note the range of variation and degree of scientific confidence in the numbers reported. Land use and management changes are divided into groups based on scientific confidence in their positive sequestration values. The high-confidence group includes conversion of annual row crops to forests, short-rotation woody crops, and wetlands. The low-confidence group includes conservation tillage[2] and increased diversity of plant species. Although these latter practices have recognized environmental benefits, their carbon sequestration benefits are uncertain.

Increasing the amount of carbon sequestered is but one of numerous benefits resulting from these land use and management changes. Most of the listed sequestration techniques are best management practices (BMPs) well known and widely used to protect or enhance soil, water, wildlife, and social values. Reforestation and afforestation (planting trees on converted forestland) protects and stabilizes soils, regulates stream flows, and provides habitat niches for different wildlife communities. Forestation, short-rotation woody crops, and increased forest stocking increase timber supplies and biomass fuels. Establishing prairie and wetlands on land retirements, riparian buffers, and marginal land moderates flood pulses, reduces turbidity and excess nutrients in waterways, and increases wildlife habitat and biodiversity. Converting marginal cropland to pasture and managing soil carbon enhances soil fertility and moisture retention, reduces erosion, and contributes to regional water quality protection and floodwater retention. These BMPs can also be useful in adapting to a warming climate and increasing incidences of flooding, drought, and other negative consequences of climate change.

Table 1 notes:
^Estimates refer to a timeframe of ca. 50 yr, except for short-rotation woody crops where estimates apply only to the duration of the stand rotation.
[£]Based on coefficient of variation (CV): CV<40% -High; CV 41-80% - Medium; CV >81% - Low.
[*]Total C sequestration rate converted to CO_2-C equivalent by multiplying by 3.67.
[$]Mean, standard deviation and confidence interval values were estimated by linear regression of: row b) chronosequence data from a single study including many sites; row e) differences in biomass C accumulation between insufficiently and well-stocked forest stands in response to stand age (for stands <30 years).

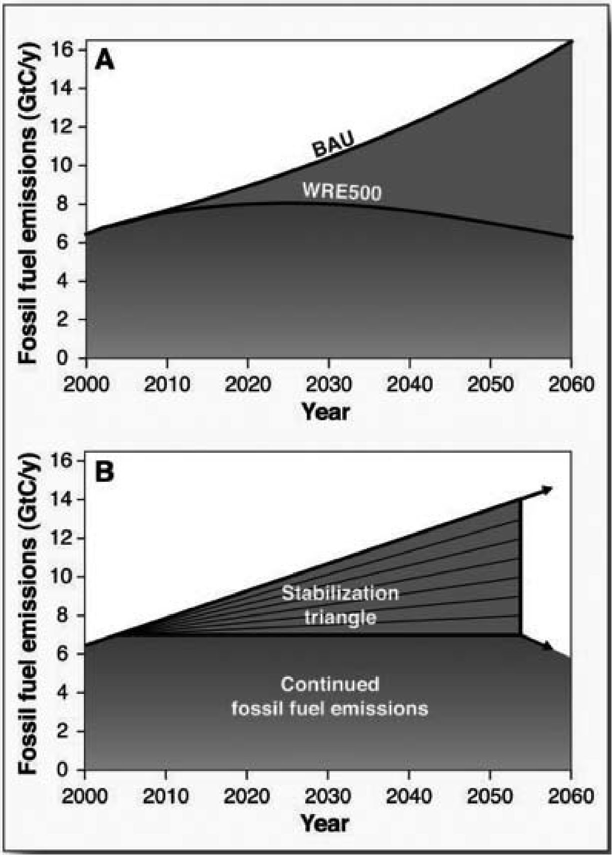

Figure 3: *Pacala and Socolow wedges*

Source: Science Magazine
http://www.sciencemag.org/.../zse0320427630001.jpeg

How might such practices be applied on farms? Including winter cover crops in annual crop rotations sequesters on average 0.6 $mtCO_2$/ac/yr. Winter rye cover crops are considered a relatively low-cost carbon sequestration technique because they do not require conversion to other land uses. The practice is widely promoted to protect against soil erosion and protect water quality and is regarded as an important strategy for replenishing soil organic carbon if corn stover or other crop residues are removed. Converting marginal lands unsuitable for crop production to perennial grasses or woody biomass increases carbon sequestration by an average of 1.6 $mtCO_2$/ac/yr and 7.0 $mtCO_2$/ac/yr respectively. The land cover change increases soil and water protection and may be a source of income in livestock and biofuel production. Planting shelterbelts and forest riparian buffers could sequester an average of 5.5 mtCO_2/ac/yr, with similar benefits.

In communities, residential and open space tree-planting programs increase carbon sequestration depending on density of plantings and can significantly reduce urban heat island effects and carbon emissions associated with heating and cooling homes. These benefits augment an already impressive list of environmental, social, and economic benefits that community forests and greenways provide.

What scale of effort is needed to make a significant contribution to greenhouse gas reduction goals? A paper influential in climate policy circles (Pacala and Socolow 2004) evaluates a portfolio of existing technologies that could be ramped up over the next 50 years to stabilize atmospheric CO_2. The analysis assigns each technology a "wedge" of reductions needed to stabilize rising emissions. The paper concludes that a massive program to increase carbon sequestration on hundreds of millions of acres of forest and farmland worldwide would be needed to produce a 10% – 20% "wedge" of global greenhouse gas emission reductions.

Using these percentages as a benchmark, several scenarios were constructed to illustrate the scale of effort needed to meet Minnesota's policy calling for a 30% reduction in greenhouse gas emissions by 2025. The scenarios are not recommendations but an example of what might be achievable over the next 15 years. The conclusion: it may be possible to increase terrestrial carbon sequestration by 3 million to 6 million metric tons of CO_2 per year, or a 6% – 12% wedge of the 45 million metric tons in greenhouse gas emission reductions by 2025. This represents a modest but important contribution to the state's emission reduction goals.

In the calculations below, the quantity of carbon sequestered by a land use practice is calculated by multiplying the carbon sequestration rate by the area of land (acres) affected. When an area of land is converted from one land use to another, the quantity of carbon sequestered is calculated by multiplying the area of land times the difference between the sequestration rates associated with the two land use practices. Often the number of years the practice will be in affect is also calculated.

The acreages used in these scenarios are meant to reflect current conditions or previous experience in Minnesota. Many variations are possible; readers are encouraged to attempt making "back of the envelope" calculations of their own.

Table 2: *The impact of lost carbon sinks on reaching emissions reductions goals.*

Land use change	C loss rate (metric tons CO_2 $acre^{-1}$)	Acres changed	Total C Loss (metric tons CO_2 yr^{-1})
Loss of forests to wildfire	367	14,600	535,820 – 1,071,640
Peatlands to annual row crops or urban	2,732	450	1,229,400
Perennial grasslands to annual row crops	1.6	144,000	230,400
Totals		NA	1,995,620 – 2,531,440

Scenario One: Potential losses from carbon sinks

The first scenario[3] focuses not on potential gains but estimated CO_2 losses from forests, wetlands, and grasslands. It projects a 14,600-acre loss of forestland based on average annual forest fire losses reported by the Minnesota Department of Natural Resources and 450 acres of peatland loss based on the most recent Minnesota Board of Water and Soil Resources report of annual net wetland loss (DNR, 2008; BWSR, 2005). Forest carbon losses from fire are estimated at 10%-20% of carbon stocks per acre (Frelich, private communication). Annual loss of forest and wetland area is multiplied by estimated carbon stock/acre in the initial land cover, because the vast majority of carbon is lost immediately upon conversion. Changes in perennial grassland is based on 2008 Farm Bill reductions in the Conservation Reserve Program, which could result in an 8% reduction of Minnesota's 1.8 million acres in CRP, primarily grasslands. Carbon losses from grassland conversion occur more slowly and are here estimated at 1.6 mt CO_2/ac/yr. The scenario assumes 144,000 acres of grassland are converted to cultivated crops upon contract expiration in 2009. Carbon losses per acre are based on estimates from MDNR peatland inventory, the USDA-NRCS STATSGO and NASIS database, LMIC land cover data, and the U.S. Forest Service FIA and Carbon Calculation Tool.

Scenario Two: Biofuels production in agriculture and forestry

The second scenario estimates the sequestration benefits of converting annual row crops to land cover types having the greatest

Table 3: *Sequestration benefits of converting row crop land to different types of cover.*

Biofuel options	**C sequestration rate (metric tons CO_2 acre^{-1} yr^{-1})**	**Acreage**	**Total C Sequestration (metric tons CO_2 yr^{-1})**
Annual row crop to forests	5.5	200,000	1,100,000
Annual row crop to short-rotation woody crops	7.0	200,000	1,400,000
Annual row crops to perennial grassland	1.6	100,000	160,000
Inclusion of cover crops in row crop rotation	0.6	600,000	360,000
Totals		1,100,000	3,020,000

potential to provide biomass feedstock for fuel and energy (e.g., forest, short-rotation woody crops, and perennial grasses). The scenario also includes adoption of cover crops in corn rotations — not as biofuels but to enable a higher proportion of crop residues to be used for biofuel without depleting soils. This scenario addresses carbon sequestration only and does not include larger CO_2 emission reductions potentially possible when renewable fuels replace fossil fuels. Land use options in this scenario also provide water quality and other environmental benefits. At the scale described below, 500,000 acres of land conversions and 600,000 acres of cover crops would be gradually implemented over the coming 15 years, and by 2025, annually sequester approximately a 6% wedge of the 45 million metric ton reduction target. Including avoided emissions would increase this wedge significantly.

Scenario Three: Multiple conservation benefits

The third scenario represents a broad conservation agenda aimed at improving water quality, wildlife habitat, forest health, and other environmental services over the coming 15 years. Numerous local, state, and federal programs exist to accomplish these objectives and could be leveraged to increase carbon sequestration. Land use and management changes proposed in this scenario total over 4 million acres, representing about 7.5% of Minnesota's total surface

Table 4: *Estimated benefits of mulitple conservation strategies.*

Multiple options	C sequestration rate (metric tons CO_2 $acre^{-1}$ yr^{-1})	Acreage	Total C Sequestration (metric tons CO_2 yr^{-1})	Loss of Working Lands
Prairie pothole restoration	4.5	300,000	1,350,000	yes
Afforestation	5.5	100,000	550,000	maybe
Annual row crop to short-rotation woody crops	7.0	100,000	700,000	no
Increased forest stocking	0.8	2,000,000	1,600,000	no
Annual row crops to pasture/hayland	0.4	300,000	120,000	no
Annual row crops to perennial grassland	1.6	700,000	1,120,000	no
Inclusion of cover crops in row crop rotation	0.6	600,000	360,000	no
Totals		4,100,000	5,800,000	

area, though much of it remains as working land. The potential gain in carbon: 5.8 Mt CO_2/yr or approximately 13% of 2025 emission reductions.

As the scenarios illustrate, large acreages will be needed to significantly contribute to Minnesota's GHG reduction goals. The table below lists carbon sequestration techniques most optimal for large-scale adoption in different eco-regions. How effectively different strategies can be applied and scaled up without compromising economic and environmental resources will be essential to win broad social support now and in the future. Among the numerous avenues for complementary action are major economic and conservation programs, including water quality improvement, flood protection, sustainable forestry, urban greenways, fish and

Table 5: *Opportunities for Improved Carbon Management, by Minnesota eco-region.*

Eco - Region	Complementary land use / management
Northwest Tallgrass Aspen Parklands	• Grassland establishment (native and perennial) • Woody and grass biofuel production • Improved pasture and hayland management • Wetland restoration
Northeast Mixed Forests	• Woody biofuel production • Improved pasture and hayland management • Enhanced stocking forest & shrublands • Ecological restoration of public forests
Central Broadleaf Forest	• Woody biofuel production • Cover crops on annual row crops • Afforestation / Reforestation(restoring former forestland back to forest) • Improved pasture and hayland management • Grassland establishment (native and perennials)
West and Southwest Prairie	• Grass biofuel production • Cover crops (south-central) • Improved pasture and hayland management • Grassland establishment (native and perennial) • Wetland restoration
Urban Areas	• Urban / community forests • Wetland restoration • Afforestation / Reforestation

wildlife protection and restoration, and biofuel production.

Recommendations

The findings and analysis presented above lead the Minnesota Terrestrial Carbon Sequestration Initiative to recommend a three-step program to policymakers.

Recommendation #1: Preserve existing large carbon stocks in peatlands and forests by identifying and protecting areas vulnerable to conversion, fire, and other preventable threats.

Forests and peatlands contain very large carbon stocks, estimated at 15 billion metric tons. Release of this stored carbon can result from human activities and environmental stressors. Such releases would accelerate global warming and require greater reductions in CO_2 emissions elsewhere. Vulnerable areas should be identified and stop-loss activities applied, including forest thinning and controlled burns to reduce wildfires, discouraging loss of natural vegetation in development, and avoiding mining, drainage, and cultivation of organic soils. Similar efforts to reduce conversion of perennial grasses should be considered. Applicable programs on private land include Forest Legacy Program, Native Prairie Bank, Reinvest in Minnesota, Wetlands Conservation Act, and programs of private organizations.

*Recommendation #2***:** *Promote land use and land cover changes most certain to cause carbon sequestration by including them in local, regional, and statewide conservation, renewable energy, and sustainable development priorities.*

Wide differences exist in the carbon sequestration benefits of the thirteen land use, land cover, and management changes most applicable in Minnesota. The most prudent approach in the near term is to incorporate carbon objectives into broader environmental, economic, and renewable energy programs, with a focus on those land use/cover/management changes with the highest sequestration rates and medium to high certainty regarding their positive sequestration value. Numerous public and private programs to improve water quality, flood protection, forest productivity, and biodiversity could increase carbon benefits at little additional cost. Designing programs to integrate climate mitigation (lessening CO_2 buildup) and adaptation (reducing its impacts) could help address costs and uncertainties of sequestration projects and increase long-term public support.

Recommendation #3: Invest in monitoring and demonstration programs to build public, practitioner, and investor confidence in terrestrial carbon sequestration as a viable emission reduction strategy.

A major conclusion of this assessment is that protecting and enhancing the state's carbon stocks is an important resource management strategy needing research and education to be implemented successfully. However, given the uncertainty surrounding rates of carbon sequestration following land use/land cover change, the state should undertake a program to establish 1) monitoring sites for quantifying carbon sequestration rates of different land use/land cover conversions and 2) demonstrations of land use/land cover changes that are most promising for carbon sequestration. Such a program will increase public confidence in the viability of terrestrial carbon sequestration as a CO_2 mitigation strategy.

The monitoring and demonstration network envisions a linked system in which a small number of monitoring sites complement and inform an extensive network of demonstration projects around the state.

The purpose of a monitoring network is to assess changes in the state's net carbon balance related to land management. It would establish baselines and carry out periodic measurements of three main conditions: 1) the area of land converted from one land use to another; 2) the annual net carbon sequestration rate associated with a land use conversion; and 3) the annual rate of carbon flux between various ecosystems and the atmosphere. Measurements could be extrapolated across the region to estimate carbon sequestration resulting from land use or management changes at sites not monitored. Measurements should be obtainable in a relatively short five-year time period and should be followed up over a longer (20- to 100-year) timeframe.

Demonstration projects would be used to educate land managers about sequestration techniques; document the carbon results of selected management practices; assess financial and other costs and benefits of integrating sequestration practices into existing activities; and test applicability of various decision-making tools. Demonstrations of all sequestration techniques suitable in Minnesota should eventually be undertaken. An initial set of projects can be undertaken through collaborations with existing studies or projects around the state. Five projects are being proposed:

- *Assessing carbon impacts of sustainable forestry techniques* in the

Manitou River region north of Lake Superior. Carbon benefits of increasing forest diversity and the proportion of long-lived tree species will be evaluated, along with applicability and accuracy of forest carbon management tools.

- *Carbon benefits of wetland restorations* in the Red River Valley will investigate the compatibility of carbon management practices with flood reduction, wetland habitat, and water quality goals.
- *Carbon benefits of winter cover crops* in the Zumbro River region will be added to long-term research on cover crops by a group of farmers, local and state agencies, and University of Minnesota researchers.
- *Carbon benefits of perennial biofuels* will be assessed in partnership with Koda Energy to improve understanding of carbon sequestration implications of perennial grasses harvested for biofuel. The project builds upon an extensive study of perennial biofuel systems in central Minnesota.
- *Carbon benefits of urban forestry and green infrastructure* in the Minnehaha Creek watershed in the Twin Cities metropolitan area will be evaluated and incorporated into watershed planning.

Part II. Financing terrestrial carbon sequestration

The scale of effort described above — protecting and increasing carbon stocks on millions of acres of land — presents enormous challenges. Even if multiple-benefit strategies that leverage existing programs are used, competition for land, management expertise, and long-term commitments to sequestration practices will challenge landowners and policymakers. What financial resources could support this level of effort?

A major portion of Minnesota's existing carbon sink is forests and peatlands in the public domain. Federal and state government, and dozens of county and municipal-level agencies manage these and other open spaces for different purposes, among them wilderness protection, habitat, recreation, timber, grazing, and mining. Focusing a major effort on public lands would reap the advantages of both permanent protection and skilled management. Before undertaking such a program, it will be essential to determine if detrimental effects could occur and to promote sustainability and consistency with other goals.

Government is also the most immediate source of support for increasing carbon sequestration on private lands, using the infrastructure of private lands conservation programs built over the last century. The federal government provides billions of dollars annually in financial and technical assistance to landowners. In particular, the U.S. Department of Agriculture cost-shares many best management practices affecting carbon stocks on farmed land, wetlands, and forests. The state of Minnesota also offers assistance through cost-share programs, easements, loans, tax incentives, and other instruments in such programs as Reinvest in Minnesota, Agricultural BMP Loan Program, Sustainable Woodlands Program, Native Prairie Bank Program, and Permanent Wetland Preserves. Together these programs could provide the essential foundation for expanding carbon sequestration in the state.

In the past decade, a new paradigm has emerged for funding large-scale conservation efforts through voluntary and mandatory carbon reduction programs. The Kyoto Protocol and current and proposed programs in the United States and elsewhere utilize a "cap-and-trade," or market-based, approach for managing GHG pollution. Such programs set emission reduction targets (caps) and time tables, then provide two flexibility mechanisms that regulated sectors and companies can use for compliance. The most-commonly used mechanism is tradable allowances. Each company is issued a specific number of allowances entitling the holder to emit one metric ton of greenhouse gases (equivalent to one metric ton of CO_2, or

CO_2e). Companies can use allowances to cover internal emissions up to their cap; reserve or "bank" them for future years; or sell them to other entities. A major unresolved issue is the proportion of allowances that will be distributed for free, auctioned, and/or based on set fees.

The second flexibility mechanism refers to carbon credits, or "offsets," that companies may purchase to count against their required reduction. Carbon offsets, also denominated at one metric ton of CO_2-equivalent, are credits for emission reduction or sequestration occurring in un-capped sectors of the economy. The most common sources of offsets are renewable energy, methane collection and combustion, energy efficiency, destruction of industrial pollutants, and carbon sequestration. Economic analyses suggest that the use of carbon offsets lowers costs by 50% or more (Goulder and Nadreau, 2002), thereby increasing the political viability of compliance.

The Midwest Governor's Greenhouse Gas Accord, a consortium of nine states and two Canadian provinces aimed at reducing emissions in the region, recently completed work on a set of recommendations for a cap-and-trade program. These recommendations have been forwarded to Congress for possible inclusion in federal legislation; if enactment of national policies is delayed, the recommendations will become the basis for model rules to be adopted by Midwestern states. The recommendations call for reductions in GHGs 20% below 2005 by 2020 and 80% below 2005 by 2050. They call for a cap on emissions from electrical and industrial sectors, and on fuels used in transportation and in residential, commercial, and industrial buildings. Allowances are issued using a combination of free, auction, and fee-based distribution. Offsets may be used for up to 20% of a regulated company's total emissions. Note that this percentage refers to total emissions, not emission reductions. A company emitting 1 million tons of CO_2e per year could purchase offset credits for up to 200,000 tons of that amount.

The focus of discussion in Congress is the American Clean Energy and Security Act of 2009 offered by Rep. Henry Waxman (Calif.), specifically Title VII: The Global Warming Pollution Reduction Program. It sets annual emission reduction targets and rules for meeting them, including offset program rules. Using 2005 as a baseline, the bill calls for 42% reduction in 2030 and 83% reduction in 2050. Domestic and international offsets may be used for up to 2 billion tons of CO_2e (2,000 $MtCO_2e$) each year. The bill creates an Offsets Integrity Advisory Board to make recommendations to the U.S. Environmental Protection Agency on the establishment of the offset program, including what project types should be eligible to offset greenhouse gas emissions. The Board is expected to recommend that a single offset registry be used, along with a single set of standards for quantifying offsets and ensuring that they adequately mitigate carbon emissions. Regulation-quality standards are more rigorous than many voluntary offset programs, typically specifying that a carbon offset must be:

- *Real*, meaning the effects of a project must be comprehensively accounted for, including leakage (i.e., increases in emissions occurring elsewhere that are triggered by the existence of a project, such as increased timber harvest elsewhere because of restrictions at a project site);
- *Additional,* or "in addition to" removals that would have occurred under business-as-usual projections. Start-up dates are specified (i.e., "not before 2001") and justifications are required to explain why the project would not have occurred without carbon finance;
- *Verifiable*, meaning that effects can be measured with reasonable precision and certainty by a third-party certified verifier;
- *Permanent*, meaning that the offset project results in permanent reduction, avoidance, or removal of greenhouse gases or is backed by guarantees and safeguards to minimize and replace non-permanent removals. With few exceptions, offset registries in the United States have required an offset project to be secured by a permanent easement;
- *Enforceable*, consistent with regulations and administrative rules.

When established, the new U.S. carbon offset market will dwarf today's voluntary market, which in 2008 transacted 123 $MtCO_2e$ valued at $705 million. Although carbon offset prices have been low in the United States and volatile worldwide, they are expected to rise as GHG regulation becomes more prevalent and demand increases. A range of carbon market issues — volatility, liquidity, integrity, and enforceability of market transactions — can be expected to emerge in coming years. How they are handled will determine the level of public confidence and long-term viability of market approaches to managing pollution.

For terrestrial carbon sequestration to fully participate in these markets, advances are needed in several key areas: improved understanding of carbon sequestration; improvements in the quality, standardization, and practicality of reporting systems; avoidance of negative socio-economic and environmental impacts; and close monitoring of the impact of offsets on emission reduction efforts. This last condition refers to concern that low-cost offsets will deflect attention from more expensive replacement of fossil fuel combustion, the main driver of global warming. Another key consideration is the impermanence of carbon sequestration and/or the willingness of landowners to enter long-term or permanent contracts to maintain sequestered carbon stocks used as offsets.

If some types of land-based activities are not included in offset programs or if landowners opt not to participate in them, other options are possible. The Regional Greenhouse Gas Initiative (RGGI) is a nine-state cap-and-trade program operating in the Northeast United States. Rather than issuing free allowances, RGGI conducts quarterly auctions. In early 2009, auction prices were just over $3/mt CO_2e and were projected to raise $606 million during 2009. Auction proceeds are devoted primarily to energy efficiency projects, but some states also use proceeds to fund carbon sequestration projects. This strategy removes the need for strict accounting and monitoring because carbon removals are in addition to, not an offset for, capped emissions. Particularly during the early years of cap-and-trade programs, when carbon prices are low and trading mechanisms untested, the use of auction proceeds to finance carbon sequestration could have advantages by providing up-front financing, minimal accounting requirements, and low monitoring and transaction costs. In these early years, combining traditional conservation programs with carbon market auctions and offsets could provide the expertise, outreach, and finance needed for a large-scale and long-term effort.

Endnotes

[1] Geologic carbon sequestration refers to the capture of carbon dioxide emissions from industrial sources and storage in deep geologic formations.

[2] Recent research (Baker et al, 2006; Blanco-Canqui and Lal, 2008) raises questions about whether reduced tillage increases soil organic carbon or simply re-distributes it in the soil column. Although conservation tillage is an important farm practice deserving broad implementation, its carbon benefits are uncertain and need further research.

[3] This scenario has been revised to include losses from forest fire and changes in 2008 Farm Bill.

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