Commonwealth of Pennsylvania

Department of Conservation and Natural Resources

Report of the Carbon Management Advisory Group

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Executive Summary

Increasing emissions of greenhouse gases (GHG) are affecting the Earth's climate. The consensus view of scientists who study climate is represented by the work of the Intergovernmental Panel on Climate Change (IPCC). In its Fourth Assessment Report published in 2007, the IPCC concluded that global warming is "unequivocal" and that human activity is the main driver, and that serious and damaging societal and ecological impacts are likely to result.[1]

Most industrialized nations have committed to reduce their GHG emissions as part of the Kyoto Protocol to the Framework Convention on Climate Change. Political support is growing in the United States to limit GHG emissions as evidenced by a growing body of actions by states and cities, increasing support in the U.S. Congress for strong federal climate legislation, and the Bush Administration's willingness to engage in discussions on future steps to address the problem. There is little doubt that within several years, the U.S. and other nations will adopt stronger policies that limit the emissions of carbon dioxide and other greenhouse gases.

Over 50% of Pennsylvania's electricity is generated from coal. Even in a carbon-constrained world, economics will likely dictate that coal continue to be a major energy source. The key to clean energy from coal is capturing and then storing its carbon dioxide emissions in geologic formations. Forest carbon management is also important as a source of renewable bioenergy and carbon storage capability (terrestrial sequestration). Pennsylvania possesses vast potential for carbon sequestration and biomass energy within its borders, including those on state-owned and private lands. Indeed, if it can capitalize on both its substantial coal resources and biomass energy and sequestration capacity, the Commonwealth has the opportunity to develop a competitive advantage in a carbon-constrained world.

Pennsylvania's land and geology represent natural resources that will likely be crucial to the continued growth of the state's economy if and when GHG emissions are limited. The Department of Conservation and Natural Resources (DCNR), under the leadership of Secretary Michael DiBerardinis, has been investigating these resources for some time, seeking to identify a path to offsetting a significant portion of the state's GHG emissions while elevating the value of open space preservation and private lands stewardship, and informing state policy development. In 2006, DCNR created the Carbon Management Advisory Group (CMAG), a collaborative project with the Pennsylvania Environmental Council (PEC), to gather expert opinion and stakeholder input on related policy options that DCNR might pursue to promote geologic and terrestrial sequestration in the Commonwealth. This report presents the CMAG's recommendations.

[1] *See* http://www.ipcc.ch/.

The CMAG has not specified programmatic goals for DCNR but rather presents potential scenarios for carbon sequestration that are subjected to simple linear analyses in order to illustrate the potential costs and carbon benefits of different management options. This report is not intended to exhaustively analyze or rank all options, but is intended to inform and assist DCNR going forward in formulating conservation policy that takes carbon sequestration into account. It points the way to more sophisticated work in the future.

The CMAG has appropriately considered a wider group of options to address climate change than sequestration alone: sustainable economic development, energy conservation, and smart growth, to name just three examples. Such topics offer Pennsylvania's citizens benefits far beyond their costs, such as lower priced energy and increased economic opportunities. However, in order to focus the analysis on DCNR's mission and practice, those broader policy options are not discussed here.

This report, then, should be viewed as a first and preliminary step for DCNR in evaluating its programs in the context of carbon markets and potential carbon constraints. It marks the start of a journey to redefine and reapply the historic conservation mission of the agency in an emerging carbon context. Clearly, additional detailed work on a variety of fronts – both in theory and in practice - will be required, as developments warrant, for DCNR to maintain its leadership role as the chief advocate for the Commonwealth's natural resources and to meet its goal of shaping a sustainable Pennsylvania.

The CMAG's recommendations fall in four categories:

- Geologic sequestration
- Forest management
- Landscape conservation
- Greenhouse gas registries (as they relate to measuring and reporting emissions that are sequestered)

The sections below summarize the recommendations, and the full body of the CMAG report and its appendices provide additional detail.

Geologic Sequestration

Geologic sequestration can enable the Commonwealth to capture CO_2 emissions from large emitting sources (e.g., coal-fired power plants) and sequester them in underground geologic reservoirs. Assessments have shown that Pennsylvania has huge geologic sequestration opportunities where future emissions from power plants could be safely stored for at least a millennium at a reasonable cost. Most research has focused on the western counties of the Commonwealth where ample data already exists due to the long history of oil and gas exploration. The geological sequestration potential of central and eastern Pennsylvania is likely to be significant, too, but awaits evaluation.

Four categories of geological reservoirs are considered important carbon sequestration targets in Pennsylvania: 1) deep saline formations; 2) depleted and producing oil and gas fields; 3) unmineable coal beds; and 4) organic-rich (i.e., carbonaceous) Devonian-age shales. Deep saline formations constitute about 85% of the total potential, and these alone could accommodate Pennsylvania's total CO_2 emissions for roughly three hundred years.

The technology to capture and store CO_2 emissions from coal plants is coming to commercial fruition. At coal plants, CO_2 can be captured either pre-combustion (through a coal gasification process) or post-combustion. After CO_2 has been captured and pressurized, it can be transported via pipeline (or even truck, railroad, or ship) to a location where it can be geologically sequestered. At the sequestration site, the CO_2 is pumped through a wellhead down into whatever geologic formation has been identified and approved for its long-term storage. The requisite technology has been widely demonstrated, though not at a commercial scale, in the variety of contexts potentially applicable in Pennsylvania.

The cost of capturing CO_2 combined with the cost of transport, geologic sequestration, and monitoring composes the total cost of carbon capture and sequestration. Many experts conclude that widespread deployment of carbon capture and sequestration will come at costs on the order of $25 to $35 per ton of CO_2.

Carbon capture and geologic sequestration present some new legal and regulatory issues, primarily for the transportation pipelines, injection and long-term storage, and liability. These issues will need resolution before this technology can help reduce greenhouse gas GHG emissions to the atmosphere.

The CMAG's policy recommendations are as follows:

- **Develop protocols for siting and operating geologic sequestration projects in Pennsylvania**.

Such protocols should rely on *inter alia*: improved databases on potential sites and pipeline infrastructure, careful geologic assessments and site evaluations, a sophisticated geographic information system (GIS) to aid decision-making, and a comprehensive risk assessment that informs the necessary legal and regulatory framework to govern sequestration activities.

The Commonwealth should establish an appropriate legal and regulatory framework for geologic sequestration. The Department of Environmental Protection is the natural lead agency, but there are important potential roles for DCNR and other agencies. The Commonwealth should also work with interested state and federal officials to promote a consistent multi-state and/or national legal and regulatory framework to govern geologic sequestration.

- **Develop a pilot project to demonstrate geologic sequestration in western Pennsylvania.**

Funding could come from some combination of: private companies, state government, MRCSP, and/or other federal programs, including funding authorized by the Energy Independence and Security Act of 2007 and FutureGen programs. A successful demonstration would provide valuable information and experience to guide future sequestration projects. Western Pennsylvania provides a variety of attractive sites that could test multiple types of reservoirs with large CO_2 emission sources close by.

There are also numerous large sources of CO_2 that could supply the gas for a pilot project: power plants and other industrial facilities. Deep saline aquifers have the potential to store the largest volumes of CO_2. However, pilots should also be explored for the other three types of formation because they have the potential to enhance oil and gas production and thus produce a revenue stream that could defray the costs of the pilot.

- **Develop a pilot project to demonstrate geologic sequestration in conjunction with coalbed methane production in the anthracite region of northeastern Pennsylvania.**

Funding could come from sources noted above, and a pilot would yield similar valuable information and data. Northeastern Pennsylvania offers many potential sites.

Pennsylvania's anthracite coal fields have substantial potential for production of methane, but this potential has not been studied thoroughly to date. DCNR's Bureau of Topographic and Geologic Survey (BTGS) and the U.S. Geologic Survey have explored a joint venture that would conduct a pilot project involving industry partners as well. A successful pilot could open the doors to significant geologic sequestration as well as enhanced methane production in the Appalachian basin.

Forest Management

Pennsylvania's public and private forests annually sequester about 5% of the state's greenhouse gas emissions. Over half of the state's forest lands are in private ownership, and 29% are in public ownership. The State Forest comprises 12% of the forested area of the Commonwealth, and provides high quality forests products, energy, water purification, recreation, mineral resources, aesthetic value, and vital habitat for the state's wildlife.

Sustainably managed forests will store carbon for decades (and also provide multiple ecosystem benefits such as improved water quality, habitat, and biodiversity).Durable products made from wood may store carbon for even longer. Because loss of forests to development results in a one-time surge of GHG emissions to the atmosphere as well as forgone future sequestration, reducing the rate of forest conversion is the most important policy recommendation in the forest sector. Options to mitigate this loss of forest land are described in the Landscape Preservation policy recommendations.

Other forest recommendations will contribute to enhanced C storage on existing land, and are described in detail in Chapter 3 and Appendix C. These recommendations relate specifically to: (a) sequestering more carbon through sustainable forest management; (b) restocking understocked forest to a fully stocked condition; (c) enhancing use of wood feedstocks for electricity and liquid fuel production; (d) increasing production and use of durable wood products; (e) planting trees in urban and suburban areas, and (f) planting vegetation on underutilized land.

Planting vegetation on underutilized land can contribute to enhanced C sequestration if the land utilized for this purpose was not already in forest cover. Planting of non-traditional crops, such as switchgrass or short-rotation woody crops, can have a marked GHG impact if the benefit of fuel switching is also added to the overall GHG benefit. Afforestation and planting can be expensive, however, especially if site preparation is also required.

The potential exists to produce electricity from wood biomass, but it would be impossible to replace 100% of PA's coal-based electricity with biomass energy from wood produced in-state. Even if all of the available biomass in PA were directed for this purpose, at most about 13% of annual PA electricity demand might be met with biomass fuels.

The potential also exists to produce cellulosic ethanol from wood biomass, but this technology is not yet fully mature. As with producing electricity from wood, supply issues are critical. If the volume of cellulosic ethanol from producers currently considering locations in PA were to quadruple, the biomass feedstock need would actually exceed by 0.4 million tons the highest predictions of annual biomass availability statewide. At this high level of wood utilization, the resultant ethanol would meet only 6.4% of 2005 annual transportation fuel demand in PA.

Increasing C sequestration on existing forest land could provide a GHG benefit. This can be achieved in two ways (outside of ensuring natural regeneration): restocking understocked stands and/or increasing the acreage under certified management. Since a one-time surge in C emissions occurs with tree harvest, however, if understocked forests are harvested first, then replanted – even if the replanted forest is fully stocked – the one-time surge of emissions from harvest will vastly outweigh the small annual sequestration benefit from the replanted acres. An alternative option would be to increase the forest acreage currently under certified management. At relatively little cost, this option would likely enhance C storage in existing forest without the one-time surge from a large-scale harvest operation.

Planting trees in urban and suburban areas is quite promising. This option leads to both enhanced sequestration in planted trees, and fossil fuel offsets in the form of reduced demand for heating and cooling. Because of the additional economic benefits of urban trees, the net benefit for this option is negative, meaning that the recommendation results in a cost savings.

The CMAG's policy recommendations are as follows:

- **Consider planting vegetation on underutilized land such as abandoned minelands, oil & gas well sites, brownfields, marginal agricultural land, and riparian areas.**

Depending on the type of vegetation established, the benefits from this option include both sequestration in terrestrial systems where vegetation is planted and offsets from fuel switching where cellulosic feedstocks (such as short-rotation woody crops or switchgrass) might be used to produce renewable fuel. There is significant land in these land use types, especially in land classified as marginal for agriculture. Opportunity costs on underutilized lands are low, such that significant GHG benefit could be achieved; however, absolute costs are considerable..

- **Increase sequestration on managed forests in PA.**

Managed forests can sequester more C annually than unmanaged forests. This is accomplished by utilizing materials from thinnings for energy to offset fossil fuels consumption, calculating the long term storage of carbon in durable wood products from harvested wood, and successfully regenerating the harvested forest to meet or exceed previous sequestration rates. Therefore, increasing the acreage under actual forest management will enhance the terrestrial C storage potential for existing forests in PA. Further, land under certified management is eligible to generate offset credits[2]. While an additional mechanism for achieving this benefit might be through restocking of understocked stands, the net benefit of this recommendation depends on the method used for restocking. Restocking can result in a net C emission if forest harvest takes place before replanting in the fully stocked condition.

- **Consider using local wood for small scale local district combined heat and power and liquid fuel production, etc. but pay close attention to biomass supply.**

Under the most optimistic available projections for annual sustainable biomass supply (6 million tons/ year statewide), if all of that supply was harvested (ignoring availability and accessibility issues) and was used for electricity production, using in-state biomass for this option will offset 13% of existing electricity demand in PA. Similarly, if all of the estimated sustainable biomass supply (6 million tons/ year) was used for cellulosic ethanol production, 6% of PA's annual transportation fuel demand would likely be met with ethanol produced in-state.

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[2] Chicago Climate Exchange (CCX) – Forestry Contracts - http://www.chicagoclimatex.com/content.jsf?id=242

The Commonwealth's biomass resources and the potential sources of plantation biomass are diffused over a large patchwork landscape. Estimates of total biomass volume based on sustainability are likely to prove optimistic when accounting for management limitations and economic considerations (transportation, fuel costs, access, competing markets for low-value wood).

Market forces will determine the availability of wood and the impact on competing uses and users. The data presented to the CMAG strongly suggest that the sustainability of large-scale operations that require huge volumes of feedstock annually is far from certain.

However, a large group of locally focused/financed small projects spread widely across the Commonwealth could capture both the value of replacing high-cost fuel imports and significant carbon benefits while also limiting transportation costs of the feedstock. A local energy generation model has potential to allow displacement of significant quantities of current or projected fossil carbon emissions across a broad spectrum of users – industry, public institutions, commercial offices, and multi-family buildings - through reduced electrically-driven cooling, replacement of fossil fuel-based heat, and distributed generation of electricity through combined heat and power facilities.

Such an approach offers significant possibilities for decentralized, economically and environmentally sustainable rural economic development through community-based independent power production. Further, small-scale projects, when deployed across the Commonwealth, can cumulatively provide significant emissions offsets that are at least comparable to those that may be afforded by a lesser number of large-scale projects (e.g. cellulosic ethanol utilizing forest resources) while providing considerable co-benefits – energy independence (keeping energy dollars very local), taxpayer savings, rural economic opportunity, maximizing carbon sequestration in the local forests, and improved water quality, habitat and biodiversity. A detailed analysis of this model is beyond the work of CMAG, but the concept merits serious consideration for policymakers, communities, energy practitioners, and energy users.

The Sustainability Imperative

In considering forestland as a source of biomass energy feedstocks, sustainability is the most critical issue facing Pennsylvania in shifting energy production to those resources. The Commonwealth's sustainable biomass yield is limited, and while it can be augmented with the development of short rotation crops and other measures, policy relative to biomass energy development must avoid a scenario that inadvertently incentivizes deforestation or conversion of large portions of native forests to short rotation plantation, with consequent impact to the suite of ecological and environmental values that the state's forests are so critical in providing. As with other areas of carbon reduction and alternative energy, a portfolio approach is needed.

- **Provide incentives to process wood into durable wood products.**

Long-term storage in products "in use" can contribute to overall C storage. This benefit, however, is quite small compared to the other options considered. Additional benefit might be achieved if emphasis were placed on substituting wood materials for other building materials - such as steel and concrete - that contain substantially more embodied energy.

- **Plant trees in urban areas.**

This option results in a substantial net economic benefit, because the benefits of planting (and retaining) trees in urban areas in terms of clean air and water provision, aesthetic benefits, and reduced fuel use outweigh the costs of tree planting and maintenance. GHG benefits of urban tree planting are twofold: C is stored in the trees themselves, and trees provide shade, which reduces the fossil fuel demand primarily for cooling.

The various Forest Management options interrelate. They present opportunities to create synergy among them. However, a more sophisticated analysis of priorities and strategies for maximum cost/benefit impact will require further work beyond the CMAG process.

While the absolute amount of sequestration across all of the scenarios analyzed relative to the state's total emissions is relatively small, the carbon sequestration capabilities that Pennsylvania's forests can provide will play an important role as a CO_2 emission offset as part of a portfolio of emission offset/reduction strategies that will be needed to reduce C emissions to sustainable levels. Similarly, the amount of electricity or liquid transportation fuels that can be sustainably derived from Pennsylvania's forest lands is modest, but important. With the advent of cellulosic ethanol technology, the estimated sustainable biomass yield could, if dedicated to the production of liquid transportation fuels alone (ignoring availability and accessibility issues), sustain the ethanol component of an E10 gasoline standard from in-state forest resources. In addition to these values, with the adoption of carbon constraints, there is a strong potential that a cash value will be placed on the carbon captured and stored by many of the forestry options analyzed by the CMAG. That emerging market will significantly impact the absolute cost and the cost effectiveness of the scenarios analyzed here.

Land Conservation

In Pennsylvania, the Natural Resources Inventory (NRI) estimated that there are roughly 15.5 million acres of forest in 1997. Between 1982 and 1997, 902,900 acres of forest were converted to non-forest use (61,393 acres annually). Of this total, 597,900 acres were converted to developed use, for a net annual loss of 39,860 forested acres to development statewide. This corresponds to a net forest loss of 0.40% year to all non-forest uses, or 0.26% loss annually to development. Indeed, Pennsylvania – one of the slowest growing states in the nation – converts more land per person to low-density developed use than every other state except Wyoming. Because forest conversion to developed use results in a one-time surge of C emissions while foregoing future carbon sequestration, protecting forest land, thereby avoiding C emissions that would otherwise have taken place, constitutes a significant GHG benefit.

The policy recommendations in the Landscape Preservation sector seek to examine the carbon benefit from various land conservation scenarios. Conservation might be accomplished in two ways: a) direct DCNR purchase of forest land that might otherwise be converted, and b) incentives that seek to reduce the rate of conversion of privately-owned land. The GHG benefit is twofold: avoided C emissions that might otherwise have taken place on converted acreage, and C storage on cumulative protected acreage. While the GHG benefit in both cases is the same, the two mechanisms differ in terms of the per-acre cost. Direct DCNR purchase of land is expected to cost $1,750 per acre, while the cost of easements for protecting private land is expected to cost $1,500 per acre.

The CMAG's policy recommendations are as follows:

- **Consider direct DCNR acquisition and protection of forest land.**

Since all of the protected land would be purchased, the benefit of this option is greatest where one assumes that 100% of the converted land would otherwise have been developed.

- **Develop incentives for protection of forest land from conversion to developed use.**

Again, the benefit and cost-effectiveness of this option is greatest in forests where it is most likely that conversion might otherwise have taken place.

Land conservation brings with it significant GHG benefits. Its importance as a GHG mitigation strategy will increase with the imposition of carbon constraints. Inducing private forest land owners to manage for carbon value, in addition to other resource values, will require a shift in mind set and economics.

Registries

In anticipation of possible legislation which could create a cap-and-trade system or other mandatory GHG policies, there have been federal, state, and private efforts to establish GHG registries, i.e., a standardized and transparent approach to accounting practices that measure emissions and/or sequestration efforts by GHG-producing entities such as governments, businesses, etc. Registry protocols also address quantification standards and verification procedures. The CMAG aimed to identify policy opportunities that would encourage maximum possible participation in carbon markets by owners of the Commonwealth's terrestrial and geologic sequestration resources.

During the course of the CMAG process, negotiations among many states concluded and resulted in the creation of the Climate Registry,[3] a merger of several state and regional efforts that will begin to establish a national protocol aimed at managing a common greenhouse gas emissions reporting system. It will be capable of supporting various greenhouse gas emission reporting and reduction policies for its member states, tribes, and reporting entities. It will provide an accurate, consistent, transparent and verified set of emissions and carbon storage data from reporting entities, supported by a robust accounting and verification infrastructure. Thanks to the leadership of Governor Edward Rendell, Pennsylvania became a member of the Climate Registry in 2007, and now has the opportunity to develop and ensure its success. The CMAG's registry recommendations are intended to support and guide Pennsylvania's participation in the Climate Registry, and in other relevant efforts.[4]

The CMAG agreed on the following purposes for a registry:

- Support implementation of comprehensive statewide climate mitigation actions related to Forestry and Geologic resources.
- Establish quantitative implementation baselines for current and future state policies, programs and projects.
- Report and track progress of current and future state policies, programs and projects in terms of greenhouse gas emissions reductions made in implementing state mitigation actions.
- Enable reciprocal disclosure, recognition and reward of climate mitigation actions at the local, state and multi state level.

The CMAG compared current registry designs at the state, regional and national level, and developed specific guidance for 16 key registry design parameters to support CMAG forestry and geologic resources options:

1. Voluntary or mandatory status
2. Greenhouse gases covered
3. Scope and scale of emissions/sinks covered
4. Organizational boundaries
5. Level of aggregation
6. Eligible sectors and sub-sector activities
7. Eligible implementation mechanisms
8. Timing of base year and baselines

[3] *See* http://theclimateregistry.org.
[4] *See* http://www.pi.energy.gov/enhancingGHGregistry/sitemap.html.

9. Emissions measurement, verification & monitoring methods
10. Emission reductions measurement methods
11. Eligibility and rules for offsets, credits, baseline protection
12. Reporting & recordkeeping requirements
13. Cost and membership criteria
14. Geographic coverage and reciprocity
15. Time period and duration of actions
16. Incremental effects beyond baseline

The detailed recommendations appear in Chapter 5. They identify key design parameters that must be considered carefully if all of the owners of Pennsylvania's terrestrial and geologic sequestration resources are to be positioned favorably to participate in carbon markets. These recommendations should serve as critical guidance to the positions the Commonwealth advocates in its participation in the Climate Registry.

Conclusion

Climate change calls upon DCNR to develop a new conservation practice that considers the Commonwealth's natural resources as competitive advantages in a carbon-contrained world. Geologic and terrestrial carbon sequestration can create new economic and environmental values for sustainable public and private land management, and the public lands can lead the way in advancing this work. Carbon credit trading can create incentives for sustainable forestry practices, and protecting land from deforestation can have increased value under carbon limitations. And, with careful planning, public lands can sustainably provide a range of alternative energy sources. All of these activities can contribute reductions to Pennsylvania's greenhouse gas emissions.

The CMAG has provided important early guidance to DCNR as it begins the challenging work of viewing its conservation practice through a carbon lens. Going forward, DCNR will continue to inform state policy development. The agency will look for opportunities to undertake pilot projects to advance its practice, and will develop appropriate education and outreach efforts to the Commonwealth's citizens, landowners, and businesses.

Foreword from Secretary Michael DiBerardinis

Since taking office as Secretary of the Department of Conservation and Natural Resources in 2003, I have had the opportunity to see the important role that DCNR's lands, facilities and programs have in the lives of Pennsylvanians. DCNR has a core responsibility to our historic mission, which is to protect and enhance the resources entrusted to us. We also have tremendous opportunity to broaden our mission and help to shape a sustainable Pennsylvania.

Climate change is perhaps the single biggest long-term threat to Pennsylvania's existing natural heritage and the sustainability of our economy. DCNR's stewardship and sustainability mission demands that we rise to the challenges of understanding and addressing this threat within the context of our work in a serious, thoughtful, and creative manner.

In forming the Carbon Management Advisory Group (CMAG) in August, 2006, we set as our goal to understand and contextualize Pennsylvania's forest, geologic, and biomass resources in new ways, and to assess their potential to provide the Commonwealth with a competitive advantage in a future carbon-constrained world. We have sought to identify a path to offsetting a significant portion of the Commonwealth's greenhouse gas emissions and providing carbon-neutral energy by effectively utilizing those resources while capturing co-benefits. We have worked to develop a meaningful carbon management plan that is compatible with DCNR's core mission programs even as it opens the way for future innovation.

It is my hope that by pursuing these opportunities, we will elevate the value of open space preservation and private lands stewardship, inform state policy and practice, and assist the Commonwealth in successfully meeting the challenges of a carbon-constrained world.

I would like to express my deep appreciation for the energy and commitment that every member of the CMAG brought to this effort. The insights, expertise, and contributions of our stakeholders were invaluable. DCNR staff rose to yet another challenge and applied their unsurpassed talents to this complex task. The Pennsylvania Environmental Council and The Center for Climate Strategies have been superb and valued partners in helping our agency take the first steps in this new phase of our stewardship mission. I thank them all.

Michael DiBerardinis
Secretary, DCNR

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DCNR and PEC also recognize and appreciate the many individuals who participated as stakeholders in the project (see following page).

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Chapter 1
Background and Introduction

Developments in the twenty-first century have led to a shift in the debate surrounding global climate change. In a relatively short time period widespread consensus has emerged that the earth's climate is changing, and that, contrary to the long standing counter argument, humans are playing a significant role. The culprit is a category of gases that inhibit the earth's ability to reflect heat away from itself, and have been categorized as greenhouse gases (GHGs). They are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6). These gases all possess varying levels of heat trapping capability and are expressed in carbon emission and offset discussions as emission reduction units as CO_2 equivalents, indicating their Global Warming Potential (GWP). For example, carbon dioxide represents a unit of one, whereas methane, on a per unit basis, has 21 times the heat trapping capability, would represent 21 units on a CO_2 equivalent basis.

Global Warming Potential (GWP)[1]

The concept of a global warming potential (GWP) was developed to compare the ability of each greenhouse gas to trap heat in the atmosphere relative to another gas. The definition of a GWP for a particular greenhouse gas is the ratio of heat trapped by one unit mass of the greenhouse gas to that of one unit mass of CO_2 over a specified time period.

As part of its scientific assessments of climate change, the Intergovernmental Panel of Climate Change (IPCC) has published reference values for GWPs of several greenhouse gases. While the most current estimates for GWPs are listed in the IPCC's Third Assessment Report (TAR), EPA analyses use the 100-year GWPs listed in the IPCC's Second Assessment Report (SAR) to be consistent with the international standards under the United Nations Framework Convention on Climate Change (UNFCCC) (IPCC, 1996)[2]. (See the table titled Global Warming Potentials and Atmospheric Lifetimes[3] for a listing of GWPs and atmospheric lifetimes of methane and the other major species of greenhouse gases for comparison.).

These are the values from the SAR:

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1 http://epa.gov/highgwp/scientific.html
2 http://www.ipcc.ch/
3 http://www.epa.gov/climatechange/economics/index.html

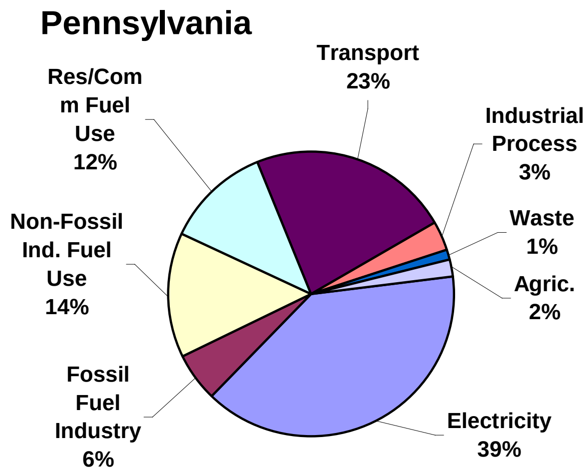
Greenhouse Gas	Global Warming Potential
Carbon Dioxide (CO2)	1
Methane (CH4)	21
Nitrous Oxide (N2O)	310
Sulphur Hexafluoride (SF6)	23,900
Perfluorocarbons (PFC)	7,000
Hydrofluorocarbons (HFC)	1,300

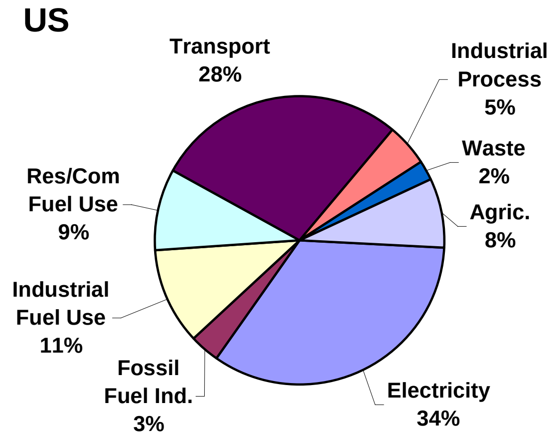
To convert from units of carbon to units of CO_2, multiply carbon by 44/12. This represents the ratio of the molar weight of CO_2 (44 grams per mole) to the molar weigh of carbon (12 grams per mole).

This discussion is relevant to Pennsylvania given that it ranks third, following Texas and California, in GHG emissions nationally. It is estimated that emissions in 2005 totaled 317 million metric tons of gross carbon dioxide equivalent, or equal to 4% of total gross US GHG emissions.[4] Emissions contributions by sector and comparison within the Commonwealth and nationally can be seen in Figure 1, also from the *Pennsylvania Greenhouse Gas Inventory*.

[4] *Pennsylvania Greenhouse Gas Inventory and Reference Case Projections: 1990-2025*, p.6.

Figure 1. Gross GHG Emissions by Sector and Gas, 2005, Pennsylvania and US



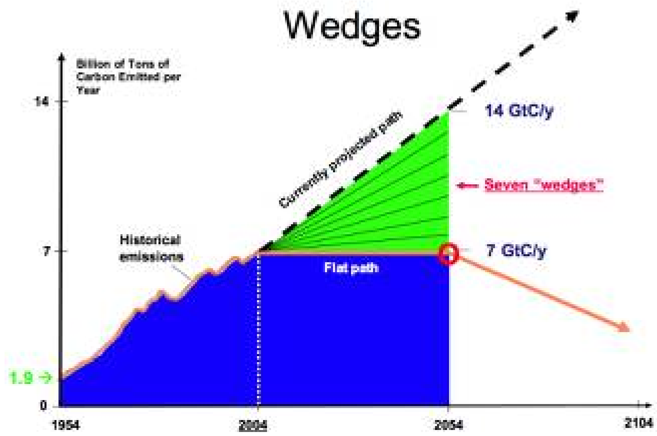


The consensus view of scientists who study climate is represented by the work of the Intergovernmental Panel on Climate Change (IPCC). In its Fourth Assessment Report published in 2007, the IPCC concluded that global warming is "unequivocal" and that human activity is the main driver, and that serious and damaging societal and ecological impacts are likely to result.[5]

Although it would be convenient if there were a silver bullet to solve all of these challenges, there is widespread recognition that it's going to require something more like "silver buckshot."

Perhaps the best example of this is Pacala and Socolow's work published in *Science*, August 2004 "*Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies.*"

[5] *See* http://www.ipcc.ch/.



Geologic sequestration, terrestrial sequestration and biomass for energy are identified as wedges, and when combined with other options, can contribute significantly to reducing the Commonwealths national and global GHG contribution.

Over 20 states have adopted climate action plans or are developing such plans.[6] Over 600 mayors have signed the Mayors' Climate Protection Agreement.[7] Most industrialized nations have committed to reduce their GHG emissions as part of the Kyoto Protocol to the Framework Convention on Climate Change. Political support is growing in the United States to limit GHG emissions as evidenced by the increasing support in the U.S. Congress for strong federal climate legislation, and the Bush Administration's willingness to engage in discussions on future steps to address the problem. There is little doubt that within several years, the U.S. and other nations will adopt stronger policies that limit the emissions of carbon dioxide and other greenhouse gases.

Pennsylvania's land and geology represent natural resources that will likely be crucial to the continued growth of the state's economy when GHG emissions are limited. Currently Pennsylvania produces over half of its electricity from coal, and even in a carbon-constrained world, coal will likely continue its key role in powering the Commonwealth. The key to making coal a "clean" energy source is capturing and then sequestering its carbon dioxide (CO_2) emissions in geologic formations (carbon capture and storage), supplemented by a range of other carbon management actions, including expanded biomass energy use and protection or expansion of terrestrial sequestration of CO_2 emissions in forests and soils. Pennsylvania possesses vast potential for both geologic and terrestrial sequestration as well as biomass energy within its borders, including those on state-owned and private lands. Indeed, with its substantial coal resources and sequestration capacity, combined with forest carbon management and other critical actions across all sectors, the Commonwealth has the ability to develop a competitive advantage in a carbon-constrained world.

The Department of Conservation and Natural Resources (DCNR), under the leadership of Secretary Michael DiBerardinis, has been investigating sequestration and sustainable

[6] *See* www.climatestrategies.us.
[7] *See* www.coolmayors.org.

forest carbon management for some time, seeking to identify a path to offsetting a significant portion of the state's GHG emissions while elevating the value of open space preservation and private lands stewardship, and informing state policy development. In 2006, DCNR created the Carbon Management Advisory Group (CMAG), a collaborative project with the Pennsylvania Environmental Council (PEC), to gather expert opinion and stakeholder input on related policy options that DCNR might pursue to promote geologic and terrestrial sequestration in the Commonwealth. This chapter presents some background on the CMAG's purpose and process.

Climate Change Science, Impacts, and Policy

The scientific consensus on the issue of climate change is embodied in reports issued by the Intergovernmental Panel on Climate Change (IPCC) and the National Academy of Sciences.[8] Beginning in early 2007 and stretching into November, the IPCC is releasing a series of important reports on climate change that represent its latest work (the Fourth Assessment). The release in February was a report on the Physical Science Basis of climate change. In that report, the IPCC concluded, for the first time, that global warming is "unequivocal" and that human activity is the main driver.

The second report, released in April, was on Impacts, Adaptation, and Vulnerability. It was an assessment of the harmful effects of global warming on daily life—those that are presently discernable and those that are likely to arrive in coming decades. Climate models indicate that global average temperatures could increase by 3 to 10 degrees Fahrenheit by the end of this century. Such a warming will likely result in rising sea levels, increased rainfall rates and heavy precipitation events (especially over the higher latitudes), and higher evaporation rates that would accelerate the drying of soils following rain events. With higher sea levels, coastal regions could face increased wind and flood damage, and some models predict an increase in the intensity of tropical storms. The reports warn that North America "has already experienced substantial ecosystem, social and cultural disruption from recent climate extremes," such as hurricanes and wildfires. It also predicts that ozone-related deaths from climate, now a small health risk, will turn into a substantial one.

The most recent assessment of impacts on Pennsylvania is contained in *Climate Change in the U.S. Northeast* authored by the Union of Concerned Scientists (October 2006).[9] For Pennsylvania and its Northeast neighbors, the report predicts higher average temperatures, more extreme heat days, less snow, more droughts, and more extreme precipitation events. In May, the IPCC released its third report on Mitigation of Climate Change, and the final Synthesis Report is due in November. These reports are all adding to the growing support for action on climate change.

Leading climate scientists recommend dramatic reductions in global greenhouse gas (GHG) emissions by 2050, and many states have set targets ranging from 50 to 80%.

[8] The IPCC was established jointly by the World Meteorological Organization and the United Nations Environment Programme (UNEP). More than 2,500 scientific experts from 130 countries—including the United States—participate in this effort to provide the world with a clear and objective view of the present scientific understanding of climate change. *See*: www.ipcc.ch and http://dels.nas.edu/globalchange/.
[9] *See* http://www.ucsusa.org/news/press_release/global-warming-will-alter.html.

Such reductions are necessary to stabilize the level of GHGs in our atmosphere at between 450-550 parts per million. That level, which represents roughly a doubling over pre-industrial levels, will allow us to more reasonably manage the climate impacts that are already becoming apparent.

The CMAG Process

In an effort to engage in a broad, transparent, and inclusive discussion on climate change and the role of Pennsylvania's public lands in meeting related challenges, DCNR Secretary Michael DiBerardinis created the CMAG in 2006, in partnership with the Pennsylvania Environmental Council,. The CMAG's purpose was to gather expert opinion and stakeholder input on related policy options that DCNR might pursue to promote geologic and terrestrial sequestration in the Commonwealth. The Center for Climate Strategies (CCS) provided analysis of many of the policy options presented here. The CMAG's recommendations are nonbinding on DCNR, and the Secretary of DCNR will make final decisions on policy and program implementation, where appropriate.

The CMAG followed a stepwise, joint fact-finding and policy-development process, meeting four times during 2006-2007, and holding a fifth and final public meeting in December 2007. CMAG members participated on four technical work groups formed on the topics of:

- Forestry
- Landscape conservation
- Carbon capture and sequestration
- GHG registries

These work groups met in person and via conference call multiple times during the process to develop options for CMAG consideration. Following an initial review by the CMAG and the work groups of an inventory of existing studies and activities related to DCNR programs and policies, the work groups then developed policy options and conveyed them to the CMAG. Through facilitated discussions, the CMAG sought, but did not mandate, consensus among its members on a set of policy recommendations. Options could be endorsed by consensus, or by majority or super-majority support. A record of all CMAG meetings and documents is available at http://www.dcnr.state.pa.us/info/carbon/.

There was no attempt in the CMAG process to do a traditional "benefit-cost" analysis of the recommendations. That approach would be inappropriate. DCNR and PEC recognize that no state (and indeed no nation) can solve this problem on its own. Any attempt to monetize the benefit of a single state's reduction in GHG emissions would produce a tiny number. Furthermore, benefit-cost analysis calls for discounting future benefits and costs to arrive at the net present value for a set of actions. While this methodology may be appropriate for some public policy issues and under some time horizons, the long-term nature of the effects of climate change mean that benefit-cost analysis would ascribe an inappropriately low value to the benefits to future generations resulting from climate mitigation undertaken now.[10] The CMAG process did, however, include estimation of the carbon savings potential and cost or cost savings per ton carbon saved for various options, as well as investigations of co-benefits and feasibility issues.

DCNR and PEC hope that Pennsylvanians will see the CMAG's recommendations as an important step down the road in the Commonwealth's efforts to make the best use of its natural resources in what will likely become a carbon-constrained world.

Terminology

Some jargon specific to the terrestrial sequestration discussion that are used frequently include: additionality, base year or baseline, business as usual (BAU), leakage, and permanence. We will define them here for reference:

Additionality – additionality is the amount of carbon sequestered resulting directly from a specific projects activities as compared to the amount that would have been sequestered without the project. This means there must be a specific point in time from which these changes are quantified, which leads into the establishment of a baseline or base year.

Baseline or base year – a *baseline* uses records from a specific time period to generate an average measure of the carbon stock before the initiation of a carbon project in order to then be able to calculate any additional sequestration resulting from a project's activities. A *base year* would measure the carbon stock at a specific year to serve as a reference point for future measurements.

Business as Usual (BAU) - this process involves modeling forward in time from a "base case", or known carbon stock, to predict what would occur without project action. From the "base case" to the point in time the carbon pool was projected in the future, a baseline is established in order to compare future measurements to assess carbon gains or losses.

Leakage - this is a complex term that can have many meanings in this context, entailing internal or external activities, market activities, etc. How a project is measured confounds this term, whether the protocol being used requires measurements at each individual project or entity wide. In a simple explanation – it's the term given to off-site impacts caused by a project. Perhaps the easiest example is land clearing for development. Just because an acre of land is protected here, doesn't mean that the project didn't push that development a half-a-mile down the road.

Permanence – or, what is the duration of carbon sequestration potential of any individual project? Obvious complications arise in terms of forestry activities and permanence because of the dynamics of natural systems and the probability of either anthropogenic or natural disturbances. The root of the issue deals with technological advancements that can permanently reduce a direct emission, versus a natural sink.

[10] For contrasting views on discount rates and climate change, compare The Stern Review, *After the Stern Review: reflections and responses*, *at* http://www.hm-treasury.gov.uk/media/C06/00/Paper_B.pdf with William Nordhaus, *The Stern Review on the Economics of Climate Change*, *at* http://nordhaus.econ.yale.edu/SternReviewD2.pdf.

Chapter 2
Geologic Sequestration

Recommendations in this chapter address the goal of enabling the Commonwealth to capture carbon dioxide (CO_2) emissions from large emitting sources and sequester them in underground geologic reservoirs.[1] Studies to date show that Pennsylvania has huge geologic sequestration opportunities where future emissions from centralized sources could be safely stored for at least a millennium at a reasonable cost. This sequestration capacity represents a "new" natural resource that could, if proven and fully exploited, offer the Commonwealth a competitive advantage in a carbon-constrained world.

Storage Potential in Pennsylvania

The Midwest Regional Carbon Sequestration Partnership (MRCSP)[2] conducted an assessment of geological carbon sequestration potential in a seven-state area that includes Pennsylvania. MRCSP, led by Battelle Memorial Institute of Columbus, Ohio, is a consortium of several leading universities, state geological surveys, nongovernmental organizations, and private companies charged with assessing the technical potential, economic viability, and public acceptability of carbon sequestration within the MRCSP region. The MRCSP geological team consists of a multifaceted collaboration of scientists from the geological surveys of Pennsylvania, Indiana, Kentucky, Ohio, Maryland, and West Virginia, as well as the Michigan Basin Core Research Laboratory of Western Michigan University.

The entire MRSCP region is considered to be a critical component of the nation's economy and a major producer of CO_2. The region generates almost 21 percent of the nation's electricity, 78 percent of which is derived from coal. These coal-fired power plants generate 26 percent of the nation's CO_2 emissions. The region also contains a wide array of facilities classified as CO_2 point sources, including plants that produce cement and ethylene, as well as petroleum refineries, gas processing facilities, and iron and steel mills. Phase I of the MRCSP study identified over 600 stationary facilities that are considered CO_2 point sources, of which about 300 are classified as large sources (>100,000 tons of CO_2/year) that emit over 800 million tons of CO_2 per year.

During the Phase I study, the geological team studied the regional geology of the area to delineate the most promising prospective geological reservoirs and sinks for CO_2 sequestration through data collection, interpretation, and mapping. The primary attraction of geological sequestration is the potential for direct and long-term storage of captured

[1] Much of the material in this chapter was reproduced with DCNR's permission in Chapter 8 of the Pennsylvania Climate Change Roadmap, published by PEC in June 2007.
[2] See http://198.87.0.58/.

CO_2 emissions in close proximity to the CO_2 source. Disposal wells can be drilled directly on the property of the CO_2 source in many cases, rather than having to transport the CO_2 by pipeline to a remote location. However, to achieve this objective, the potential capacity of any geological reservoir must be verified by both detailed regional and site-specific assessments to insure that decision-makers fully understand the characteristics of the geological sequestration system. For this reason, a major task of the Phase I study was a first-round regional assessment of the potential capacity for geological sequestration of CO_2 in the MRCSP area.

MRCSP's assessment in Pennsylvania included, for the most part, only the western counties of the Commonwealth. The nature of the geology, as well as a lack of sufficient well data, precluded evaluation of the central and eastern parts of the state, despite the seeming extent of mapped formations in this part of Pennsylvania. As a result, the geological sequestration potential of a large number of formations that occur only in central and eastern Pennsylvania, such as anthracite coals and Lower Cambrian formations, is currently unknown. Evaluation of these formations will require concentrated study of outcrops and a significant number of drill holes that, so far, do not exist. The cost of most such regional evaluations could be prohibitive.

Four categories of geological reservoirs are considered important carbon sequestration targets in Pennsylvania: 1) deep saline formations; 2) depleted and producing oil and gas fields; 3) unmineable coal beds; and 4) organic-rich (i.e., carbonaceous) Devonian-age shales. The sequestration capacity in Pennsylvania is unequally distributed among several deep saline formations, the Devonian shales, oil and gas fields, and coal beds. It should be pointed out that each formation has its own set of geological conditions that affect sequestering potential.

The results of Phase I of MRCSP indicate that Pennsylvania has a large potential capacity for CO2 sequestration.[3] The total amount of potential CO_2 sequestration capacity for Pennsylvania is estimated at 88.5 gigatonnes. The large majority of this sequestration capacity, about 75.6 gigatonnes (approximately 85 percent of the total estimated geological CO2 storage capacity), represents the potential of deep saline formations. This storage option alone could accommodate Pennsylvania's total CO_2 emissions for roughly three hundred years. The organic-rich shales exhibit the next largest storage potential of 12 gigatonnes, or about 14 percent of the total estimated geological CO_2 storage capacity, which may also be useful for secondary recovery of natural gas adsorbed on shale surfaces. Oil and gas fields have a potential sequestration capacity of about 7.6 gigatonnes (a little less than 1 percent of Pennsylvania's total estimated geological CO_2 storage capacity). This particular reservoir type is attractive not only for CO_2 sequestration but also for value-added enhanced oil recovery (EOR) operations, where CO_2 may be used with gas drive techniques to produce many millions of barrels of oil from existing oil fields.

[3] MRCSP Phase 1 Report, Chapter 4, p. 62, http://198.87.0.58/userdata/Phase%20I%20Report/section%204.pdf.

Pennsylvania has the largest sequestration potential in oil and gas fields of all the MRCSP partner states, representing about a third of the total MRCSP potential storage capacity in this type of reservoir. The smallest sequestration capacity is associated with coal beds, which offer less than 1 gigatonne of the total estimated geological storage capacity.

Technology and Economics

The technology to capture and store CO_2 emissions from coal plants is coming to commercial fruition and has been studied in detail by an international panel of experts and is briefly summarized here.[4] CO_2 can be captured chemically or physically from the gaseous mixture produced after coal is combusted (post-combustion capture). However, the nature of this mixture makes capturing and concentrating the CO_2 an energy intensive process, although technological improvements continue to increase its efficiency. One emerging technology called oxyfuel combustion improves the process by combusting the fuelstock with oxygen instead of typical air (which is mostly nitrogen), although producing the required oxygen itself requires energy. Yet instead of capturing CO_2 after combustion of the coal, the coal can also be gasified—a widely demonstrated technology—and the CO_2 extracted after gasification but before the resource is combusted, which tends to make carbon capture more efficient (chemically *and* economically) vis-à-vis conventional methods. Called pre-combustion capture, this method is particularly well-suited to coal-fired Integrated Gasification Combined Cycle (IGCC) electricity generation.

After CO_2 has been captured by the emission source and pressurized, the gas can then be transported via pipeline (or even truck, railroad, or ship) to a location where it can be geologically sequestered. At the sequestration site, the CO_2 is pumped through a wellhead down into whatever geologic formation has been identified and approved for its long-term storage. Likely formations in Pennsylvania include deep saline aquifers (far below sources of groundwater) or depleted natural gas or coalbed methane (CBM) fields. In fact, sequestration of CO_2 can be used to increase the output of these depleted fields. Of course, concerns for leakage and the permanence of the storage necessitate appropriate site selection and monitoring measures, even though experts consider it "likely that 99% or more of the injected CO_2 will be retained for 1000 years."[5]

The requisite technology has been widely demonstrated, though not at a commercial scale, in the variety of contexts potentially applicable in Pennsylvania. One notable project has taken the CO_2 through all of the steps (capture, transport, and sequestration). Since 1999, the Great Plains Synfuels Plant in North Dakota has captured CO_2 for transport over 200 miles to Canada's Weyburn oil field, enabling the production of over

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[4] For more detailed information on capture technology, refer to Chapter 3 of International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*. Also refer to Chapter 4 of Midwest Regional Carbon Sequestration Partnership, *MRCSP Phase I Final Report*.
[5] International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 197.

130 million barrels of petroleum (a doubling of its rate of oil recovery), while so far sequestering over five million tons of CO_2.[6] Numerous facilities around the globe will also complete each step: SaskPower in Canada, ZeroGen in Australia, RWE Power in Germany, E.ON in the United Kingdom, and FutureGen and American Electric Power in the United States (among others).[7] At least three commercial projects have demonstrated the feasibility of sequestering CO_2 emissions.[8] The Wey burn oilfield in Canada, Sleipner gas field in the North Sea, and In Salah gas field in Algeria have all been sequestering carbon (for different reasons) at similar rates of at least 3,000 tons of CO_2 per day for a combined total of over 20 years.[9] The challenge in Pennsylvania is to synthesize the elements of commercialization from projects like these around the world in order to prove and exploit the state's sequestration resources.

The cost of capturing CO_2 combined with the cost of transport, geologic sequestration, and monitoring composes the total cost of carbon capture and sequestration. More abstractly, it represents the effective cost of shifting CO_2 emissions from being vented into the atmosphere and instead sending them to a stable, safe, and long-term underground reservoir. Because the technology is rapidly developing, published cost estimates may soon (or already) be outdated, especially in forecasting what options might be available in three, five, ten, or twenty years. Although highly dependent on localized factors, the estimated cost of capture per avoided ton of CO_2 ranges from \$13-\$74.[10] The

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[6] US Department of Energy, "Practical Experience Gained During the First Twenty Years of Operation of the Great Plains Gasification Plant and Implications for Future Projects," April 2006, v, 45, and 47, http://www.fossil.energy.gov/programs/powersystems/publications/Brochures/dg_knowledge_gained.pdf.

[7] *See*: SaskPower, "Clean Coal Project," http://www.saskpower.com/pdfs/cleancoalfactsheetRVSD.pdf ; ZeroGen, "Project Overview," http://www.zerogen.com.au/files/FactSheetReviewOctober2006ProjectOverview.pdf ; RWE Power, "RWE Plans to Build a CO_2-Free Coal-Fired Power Plant Including CO_2 Storage – a Global First," press release on March 30, 2006, http://www.rwe.com/generator.aspx/presse/language=en/id=76864?pmid=4001048 ; E.ON UK, "E.ON UK Considers World-Leading Clean Coal Technology for New Pilot Power Station in Lincolnshire, Calls for Government Support," press release on May 24, 2006, http://www.eon-uk.com/pressRelease.aspx?id=937&month=5&year=2006&p=1 ; Department of Energy, "FutureGen: A Sequestration and Hydrogen Research Initiative," Project Update: December 2006, http://www.fossil.energy.gov/programs/powersystems/futuregen/Futuregen_ProjectUpdate_December2006.pdf ; and American Electric Power, "AEP to Install Carbon Capture on Two Existing Power Plants; Company Will Be First to Move Technology to Commercial Scale," press release on March 15, 2005, http://www.aep.com/newsroom/newsreleases/default.asp?dbcommand=DisplayRelease&ID=1351 ; and Michael G. Morris, "Morgan Stanley Global Electricity & Energy Conference: American Electric Power," presentation on March 15, 2007 in New York, NY, http://www.aep.com/investors/present/documents/MorganStanley_Mar-15-2007.pdf.

[8] A wealth of information and an international, searchable project database are available online with continual updates from the International Energy Agency Greenhouse Gas R&D Programme, "CO_2 Capture & Storage," http://www.co2captureandstorage.info/.

[9] International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 200-204; Statoil, "Sleipner CO_2 Project," http://www.statoil.com/statoilcom/svg00990.nsf/web/sleipneren?opendocument; and British Petroleum, "Carbon Capture and Storage," http://www.bp.com/sectiongenericarticle.do?categoryId=9007626&contentId=7014493.

[10] International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 107.

cost of transport adds only slightly to this, likely on the order of a few dollars or less;[11] and the same can be said for geologic storage.[12]

The Midwest Regional Carbon Sequestration Partnership (MRCSP) estimated a supply curve for sequestration, reproduced below as Figure 2-1 and adjusted such that the red sections represent the geologic opportunities and blue sections represent the terrestrial sequestration opportunities. While some opportunities are available below $30 per ton, most of the geologic opportunities are available from $30 per ton and upwards. This cost curve is likely to shift downward with technological improvements over the coming years. Figure 2-2 provides the MRCSP's cost estimates of carbon capture by emission source.

Many experts conclude that widespread deployment of carbon capture and sequestration will come at costs on the order of $25 to $35 per ton of CO_2.[13]

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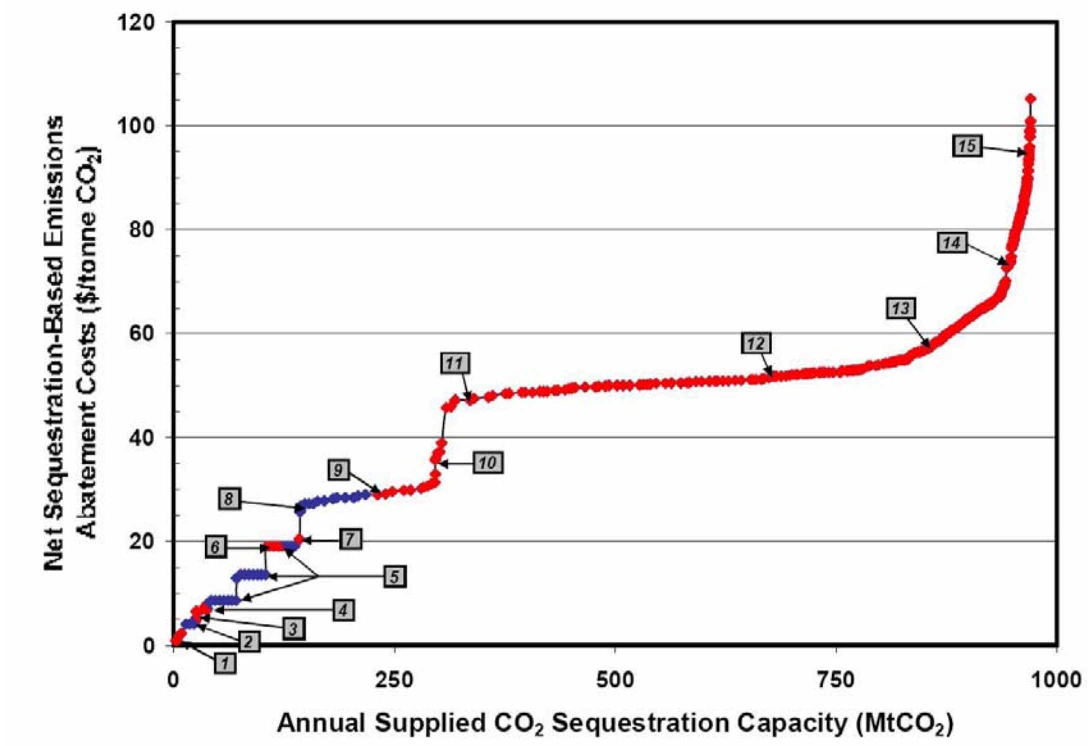
[11] The cost of transport depends largely upon the diameter of the pipeline (and, correspondingly, the rate of CO_2 flow) and the total distance covered, although terrain and population density also influence the cost; *see* International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 190-192.

[12] Based on a review of the literature and Table 5.9 of International Panel on Climate Change, *IPCC Special Report on Carbon Dioxide Capture and Storage*, 260, noting that Pennsylvania's prevailing opportunities are saline formations.

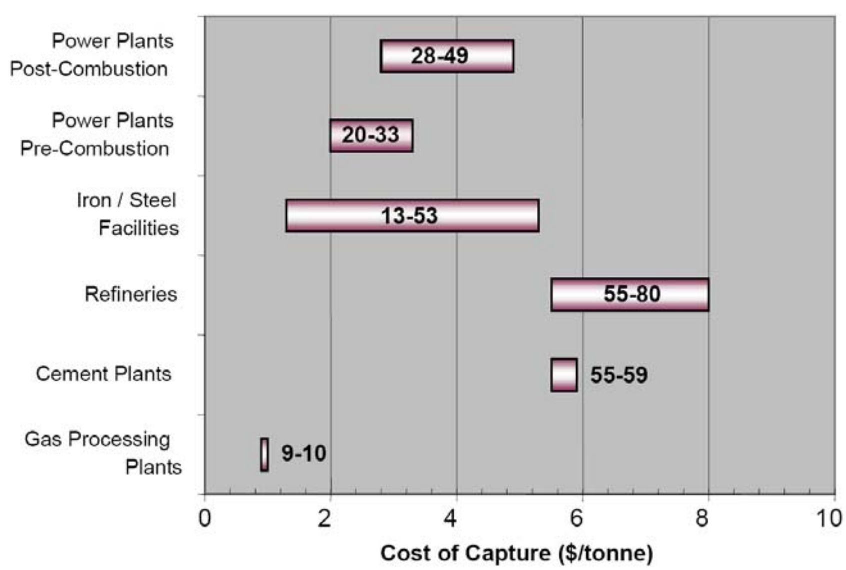
[13] A $30/t$CO_2$ estimate is given in *The Future of Coal: Options for a Carbon-Constrained World*, Massachusetts Institute of Technology, 2007, Massachusetts Institute of Technology Coal Energy Study Participants, xi, http://web.mit.edu/coal/The_Future_of_Coal.pdf. A $25-$35/tCO_2 range is cited in Robert H. Williams and David G. Hawkins, "Coal Low-Carbon Generation Obligation for US Electricity," draft, provided by Williams via e-mail on October 13, 2006, 1. A $100-$200 per ton of carbon range ($27-$55/tCO_2) is offered by Robert H. Socolow and Stephen W. Pacala, "A Plan to Keep Carbon in Check," *Scientific American*, September 2006, http://search.epnet.com/; and $100 per ton of carbon ($27/tCO_2) is offered by Howard Herzog, quoted in "Can Carbon Sequestration Solve Global Warming? Researchers Examine Limits, Promise of New Science," press release by American Association for the Advancement of Science, February 17, 2003, http://www.aaas.org/news/releases/2003/0217carbon.shtml.

Figure 2-1 Cost of Sequestration for the Midwest Region including Pennsylvania



Source: Midwest Regional Carbon Sequestration Partnership, *MRCSP Phase I Final Report*, 232.

Figure 2-2 Cost of Capturing CO_2 by Emission Source



Source: Midwest Regional Carbon Sequestration Partnership, *MRCSP Phase I Final Report*, 29.

The MRCSP also notes that few current laws and regulations are directly relevant to CO_2, though the Underground Injection Control program under the federal Safe Drinking Water Act could be relevant.

Legal and Regulatory Issues

Carbon capture and geologic sequestration present some new legal and regulatory issues, primarily for the transportation pipelines, injection and long-term storage, and liability. These issues will need resolution before this technology can help reduce greenhouse gas (GHG) emissions to the atmosphere.

The US Department of Transportation's Pipeline & Hazardous Materials Safety Administration currently oversees the nation's pipeline network via the Office of Pipeline Safety (OPS).[14] This national office partners with state agencies in most states in order to collaboratively uphold national pipeline safety regulations. The bylaws that cover CO_2 mandate "provisions for safety in the design, construction, inspection, operation, and monitoring of pipelines."[15] While Pennsylvania collaborates with OPS for some substances, the state does not participate in the program that covers CO_2 transport.[16] Therefore, in lieu of delegating authority to Pennsylvania, OPS currently retains oversight of CO_2 pipelines in the state.

An area of greater regulatory uncertainty for carbon capture and sequestration projects is the injection and storage of CO_2 underground. Currently, the Safe Drinking Water Act covers underground injection of CO_2 through the United States Environmental Protection Agency (US EPA)'s Underground Injection Control (UIC) program.[17] The fossil fuel industry has used authorized Class II wells under the UIC program to inject CO_2 for enhanced oil and gas recovery, and pilot projects sequestering CO_2 for long-term storage have recently been designated as experimental Class V wells, but larger commercial scale wells for long-term storage will likely be classified in another category, yet to be determined.[18] Ultimately, the legal and regulatory framework must determine whether CO_2 should be treated as a commodity or as waste, and as hazardous or non-hazardous.[19]

The issue of subsurface ownership must also be addressed. The complexities of land ownership and title in Pennsylvania are well-known. The cost of obtaining the mineral rights, along with potential access problems with pipeline right-of-ways and liability

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[14] For more information, please refer to the Office of Pipeline Safety's web site, "OPS Programs," http://ops.dot.gov/init/partner/partnership.htm.

[15] Partha S. Chaudhuri, Michael Murphy and Robert E. Burns, *Commissioner Primer: Carbon Dioxide Capture and Storage* (Columbus, OH: National Regulatory Research Institute, 2006), 15, http://www.nrri.ohio-state.edu/dspace/bitstream/2068/976/1/06-02+CO2+Primer.pdf.

[16] Office of Pipeline Safety's web site.

[17] For the most recent information, please see the US EPA's web site on the subject, http://www.epa.gov/safewater/uic/wells_sequestration.html.

[18] US EPA, "Using the Class V Experimental Technology Well Classification for Pilot Geologic Sequestration Projects – UIC Program Guidance (UICPG #83)," March 2007, http://www.epa.gov/safewater/uic/pdfs/guide_uic_carbonsequestration_final-03-07.pdf.

[19] Chaudhuri, *Commissioner Primer*, 19-22. For additional discussion of legal issues, see Kate Robertson, Jette Findsen and Steve Messner, *International Carbon Capture and Storage Projects Overcoming Legal Barriers* (Department of Energy and National Energy Technology Laboratory, 2006), http://www.netl.doe.gov/energy-analyses/pubs/CCSregulatorypaperFinalReport.pdf; also see Kevin Bliss, *Carbon Capture and Storage: A Regulatory Framework for States* (Oklahoma City: Interstate Oil and Gas Compact Commission, 2005), prepared for Department of Energy, http://www.iogcc.state.ok.us/PDFS/CarbonCaptureandStorageReportandSummary.pdf.

issues (discussed below) constitute a large potential hurdle to sequestration projects. Ownership issues are addressed in detail in Appendix A.

Finally, there is the issue of legal liability. Although large-scale leakage of CO_2 is considered unlikely, if such an event were to occur, it remains unclear who, if anyone, would be responsible for any harm to human health or environmental quality, let alone at what level of proof or compensation. Another liability issue concerns possible effects of large-scale sequestration on seismic activity.[20] Texas presents an interesting case study of what can be done, if deemed necessary, to provide protection from liability under the circumstances. In 2006, Texas passed a bill that transferred ownership of and responsibility for captured CO_2 to a state authority, effectively shielding the source from liability while the state may itself become protected under the legal doctrine of sovereign immunity.[21]

Policy Recommendations

- **Develop protocols for siting and operating geologic sequestration projects in Pennsylvania**. Such protocols should rely on *inter alia*: improved databases on potential sites and pipeline infrastructure, careful geologic assessments and site evaluations, a sophisticated geographic information system (GIS) to aid decision-making, and a comprehensive risk assessment that informs the necessary legal and regulatory framework to govern sequestration activities.

As noted earlier, Pennsylvania already has a relatively rich database on potential sites in western and north-central Pennsylvania due to the long history of oil and gas development in those regions and the work of the MRCSP. Data for other regions of the Commonwealth is relatively scarce, and this constitutes a hurdle to developing sites in those regions. Pennsylvania has extensive pipeline infrastructure and rights-of-way that could aid transport of CO_2 to sequestration sites, but data on this infrastructure must be handled carefully for security reasons. Improved data with appropriate access are essential to moving forward on geologic sequestration.

Much of this data should be accessible through a sophisticated GIS designed to inform both private investments and public regulation and oversight of CO_2 sequestration. Data would include the location of potential sites, storage potential of each site, and potential pipeline or other transportation infrastructure. The Commonwealth should develop the GIS, building on the basic framework already in place at DCNR's Bureau of Topographic and Geologic Survey (BTGS).

[20] DOE/NETL, *International Carbon Capture and Storage Projects Overcoming Legal Barriers,* June 23, 2006, p.23. http://www.netl.doe.gov/energy-analyses/pubs/CCSregulatorypaperFinalReport.pdf.
[21] Jay B. Stewart, "The Texas Experience," Congressional Testimony before the Energy and Air Quality Subcommittee of the House Committee on Energy and Commerce, March 2, 2007, http://energycommerce.house.gov/cmte_mtgs/110-eaq.030607.carbon_capture.shtml.

The Commonwealth should establish an appropriate legal and regulatory framework for geologic sequestration. The Department of Environmental Protection is the natural lead agency, but there are important potential roles for DCNR and other agencies. A careful and comprehensive risk assessment should provide the foundation for the legal and regulatory framework. The framework should address all the issues noted earlier.

The Commonwealth should also work with interested state and federal officials to promote a consistent multi-state and/or national legal and regulatory framework to govern geologic sequestration.

- **Develop a pilot project to demonstrate geologic sequestration in western Pennsylvania.** Funding could come from some combination of: private companies, state government, MRCSP, and/or other federal programs. A successful demonstration would provide valuable information and experience to guide future sequestration projects. Western Pennsylvania provides a variety of attractive sites that could test multiple types of reservoirs with large CO_2 emission sources close by.

There are also numerous large sources of CO_2 that could supply the gas for a pilot project: power plants and other industrial facilities. Deep saline aquifers have the potential to store the largest volumes of CO_2. However, pilots should also be explored for the other three types of formation because they have the potential to enhance oil and gas production and thus produce a revenue stream that could defray the costs of the pilot.

- **Develop a pilot project to demonstrate geologic sequestration in conjunction with coalbed methane production in the anthracite region of northeastern Pennsylvania.** Funding could come from sources noted above, and a pilot would yield similar valuable information and data. Northeastern Pennsylvania offers many potential sites.

Pennsylvania’s anthracite coal fields have substantial potential for production of methane, but this potential has not been studied thoroughly to date. BTGS and the U.S. Geologic Survey have explored a joint venture that would conduct a pilot project involving industry partners as well. A successful pilot could open the doors to significant geologic sequestration as well as enhanced methane production in the Appalachian basin.

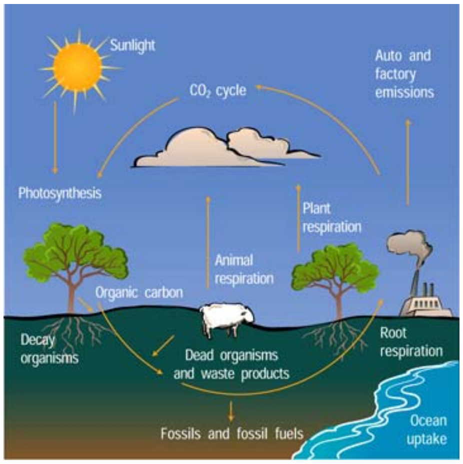
Additional detail on these policy recommendations appears in Appendix B.

Chapter 3
Forestry

Background and Introduction

Carbon is a significant base element that supports life on the planet. The carbon cycle plays a critical role in the environmental conditions on earth. Terrestrial vegetation, or trees, shrubs, and plants play a role in this system by consuming CO_2, storing carbon and producing oxygen through the process of photosynthesis. Carbon is emitted naturally when these organisms die and decay.

Figure 1 - The Carbon Cycle -



The foundation of forestry and agricultural activities being considered and/or recognized as carbon offsets originated through the work of the UN Intergovernmental Panel on Climate Change (IPCC) whose work encouraged 154 nations to sign the U.N. Framework Convention on Climate Change in 1992. This led to a series of Conference of Parties, or COP meetings, the third of which produced the “Kyoto Protocol,” which formally introduced the world to the concept of terrestrial carbon sequestration.[1]

Measurement and reporting protocols require that for an emissions reduction to be credible it has to meet a number of parameters. These are detailed in the *registry* section of this report. One of the most significant and debated issues relevant to forestry activities are the concepts of *baseline or base year establishment and Business as Usual (BAU),* which addresses that the qualifying activity has to be above and beyond what normally

[1] Carbon Sequestration: A Handbook. *Version 2.1- The National Carbon Offset Coalition*; 2005.

would have occurred. Therefore, only those activities that create additional sequestration opportunities will qualify as verifiable offsets.

Forests and Sequestration in Pennsylvania

Pennsylvania's 2.1 million-acre state forest system, found in 48 of Pennsylvania's 67 counties, comprises 12 percent of the forested area in the Commonwealth. The state forest represents one of the largest expanses of public forestland in the eastern United States, making it a truly priceless public asset. The state forest provides an abundance of high quality forest products, which help to support a forest products industry with sales in excess of $16 billion annually, a total economic impact of $27 billion annually, and employs in excess of 80,000 people. When viewed from another perspective, the state forest represents a two million acre water treatment plant and air purification system. Additionally, these forests provide recreational opportunities and mineral resources, as well as an aesthetic setting that is vital for Pennsylvania's tourism industry. And, when taken as a whole, the state forest is the largest publicly owned habitat for plants and animals in the Commonwealth of Pennsylvania. Our state forest system is a combination of these resources, uses, and values, as well as a functioning biological system with intrinsic values to be held in public trust for future generations. [2]

The US Forest Service Northern Research Station, estimates through the Forest Inventory & Analysis (FIA) Program, that between 1989 and 2002, some 17 million metric tons of carbon dioxide equivalent ($MMtCO_2e$) have been sequestered annually by Pennsylvania forests. To put this into context consider that Pennsylvania's *gross* emissions estimates for 2005, from all sources, are 317 $MMtCO_2e$.[3] The existing forests clearly provide a critical ecosystem service annually by absorbing some 5% of the Commonwealth's GHG emissions.

Pennsylvania's land area totals 28.7 million acres. Of this, 16.6 million, or fifty-eight percent, are forests. Fifty-four percent are owned by families and private individuals. Twenty-nine percent are owned by public agencies. The following table details statewide ownership categories by acres and number of owners.

[2] 2007 Pennsylvania State Forest Resource Management Plan Update; DCNR Bureau of Forestry.
[3] *Pennsylvania GHG Inventory and Reference Case Projections: 1990-2025.*

Owner category	Acres		Private owners	
	Number	Percent	Owners	Percent
	Thousands		Thousands	
Federal	611.1	4		
State	3,813.5	23		
Local	413.7	2		
Total public	4,838.3	29		
Corporate:				
Forest industry	234.0	1	<1	<1
TIMO	246.9	2	<1	<1
Misc. corporate	1,658.4	10	26.5	5
Noncorporate:				
Families and individuals	8,906.4	54	501.5	94
Noncorporate	698.1	4	4.7	1
Total private	11,743.8	71	533.0	
Total	16,582.1			

[4]

Although Pennsylvanians are blessed with an enormous public forest system, it is evident, based on the proportion of land area to ownership classifications, that much of the potential for additional carbon sequestering activities is in the Commonwealth's private forests.

Limitations

This chapter addresses the goal of enabling the Commonwealth to mitigate its carbon output by increasing carbon sequestration in its land base, expanding its use of biomass energy, recognizing carbon storage in its manufactured wood products, and recognizing the offset potentials of urban and suburban canopy cover.

The focus of the CMAG is on carbon sequestration and cost-effectiveness, and not on absolute costs. The cost calculations of the various scenarios presented herein illustrate the fiscal challenge that pursuit of any of the options would imply.

The following mitigation options are examples of additional sequestration potentials in a number of areas deemed relevant by the CMAG to forestry related activities. These were vetted out of the Advisory and Technical Work Groups (TWGs) over the duration of the project. These examples were derived within the established timeframe of the project and do not reflect long-term research findings but rather an expedient use of information in the literature and science community in what is recognized as a rapidly advancing field. Based on the variables and parameters of each individual option, estimates represent theoretical ranges or potentials.

What does all this mean? Primarily, the CMAG has concluded that any additional carbon sequestration capabilities forests can provide will play an important role as a CO_2 emission offset. These considerations are detailed in each of the following sections. Independently, each option's contribution may appear minor relative to total PA

[4] *Pennsylvania Forests 2004:USDA USFS Northern Research Station.*

emissions, but as a sum total, they can contribute significantly to the “wedge” approach to emissions offsets and reductions overviewed in Chapter 1.

Carbon Savings and Economics

Carbon savings

Carbon (C) savings for Forestry Recommendations are quantified in terms of additional C sequestered by vegetation due to policy implementation (F-2 and F-3), C stored in long-term harvested product pools (F-5), C offsets from avoided energy needs (F-4 and F-6), or a combination of these. In the specific case of forest harvest for restocking (F-3b), forest harvest prior to replanting results in a net C emission, which is then counted against the C sequestered annually in the replanted fully stocked forest.

A variety of vegetation planting scenarios were quantified (F-2, Table 3-1). Three types of vegetation (warm season grasses such as switchgrass, short-rotation woody crops (SRWC), and afforestation with typical PA forest cover) were considered for planting on five types of underutilized land (marginal agricultural land, abandoned minelands, oil & gas well sites, riparian areas, and brownfields). Since a scaled usage of the land available in each of the five land use categories was considered for each of the three types of vegetation where practical, it is not possible to arrive at a statewide estimate of the potential GHG benefit of implementing option F-2 statewide.

An overview of the analysis for all afforestation and replanting scenarios (F-2, Table 3-1) shows that replanting with typical PA forest has the highest level of cost effectiveness, regardless of the type of land being regenerated. Replanting of marginal agricultural land has by far the greatest cumulative GHG impact, because the land area is so much greater than the other land types considered.

Of the remaining policy recommendations, increasing acreage enrolled in certified management programs, increasing wood usage for ethanol production, and increasing urban and suburban canopy cover result in the greatest cumulative GHG reductions over the policy implementation period (2008-2020). Of these three, a net profit, rather than cost, is associated with the increase of urban canopy cover, due to reduction in energy use for heating and cooling. Restocking understocked forestland statewide results in net GHG emissions over the course of this study and is also a very expensive option, and therefore is probably not recommended for short-term GHG emission reduction. An analysis of the effectiveness of undertaking all options resulting in net GHG benefit at their lowest levels of implementation (F-3 A1, F-4 A1 & B1, F-5.1, F-6.1) would result in a reduction of 154.3 MMt CO_2e from 2008-2020. If all options were implemented at the highest levels calculated (F-3 A3, F-4 A2 & B3, F-5.2, F-6.3) these benefits would increase to 354.3 MMt CO_2e.

Economics

Economic analyses of afforestation costs typically employ four categories: opportunity cost (of planting forest rather than another, potentially more lucrative land use), conversion cost, maintenance cost, and measuring/ monitoring costs (Walker et al. 2007). For simplicity in the analysis of Forestry Policy Recommendations, only the direct costs of conversion (planting), maintenance, and monitoring were included. Opportunity costs vary with the type of land being considered and are quite difficult to quantify accurately. This is especially true in cases, such as agricultural production, where subsidies exist that contribute to the net economic benefit of specific existing land uses. A summary of the economic costs applied to the analysis of afforestation, planting, and regeneration, by different vegetation types on each type of land use is given in Table 3-2.

Policy Recommendations

- **Afforestation, planting, and regeneration.** This option seeks to increase carbon stored in vegetation and soils by expanding the land base associated with terrestrial carbon sequestration. Establishing new forests ("afforestation") increases the amount of carbon in biomass and soils compared to pre-existing conditions. In addition to planting forest cover, this policy option also includes consideration of planting short-rotation woody crops, such as willow and hybrid poplar[5], and warm season grasses, such as switchgrass, on a variety of underutilized land cover types. Both of these alternate vegetation types have the potential to produce biomass for energy feedstock, in addition to their carbon sequestration ability. Planting and afforestation can take place on land not currently experiencing other uses.

  Vegetation types considered for this option include short-rotation woody crops (SRWC), warm-season grasses (switchgrass), and typical PA forest. For example, willow *(Salix spp.)* is generally harvested during the dormant season on a 3-4 year cycle. Willow re-sprouts vigorously after cutting, so seven to eight harvests are obtained from a single planting. Switchgrass is a perennial warm-season grass, grown for decades on marginal lands not well suited for conventional row crops. It has been identified as a potential feedstock for cellulosic ethanol production, as well as for biomass gasification to produce electricity.

  For the biomass crops (SRWC and switchgrass), GHG benefit was calculated by first quantifying the expected yield (in million Btu) expected per acre of vegetation in PA.[6] This expected yield (in MBtu per acre) was used to calculate the expected avoided fossil fuel use from utilizing biomass as a primary energy source, assuming an existing fuel mix of equal parts oil, natural gas, and coal. Since energy is used to grow the biomass crops, however, this expected fuel switching benefit must be reduced by an amount equal to the energy inputs required to produce the crops. Energy input from agricultural machinery and fertilizer production was thus subtracted from this expected fossil fuel offset benefit, to achieve an overall GHG

[5] Short rotation woody crops could include a variety of species in addition to the examples cited; such variety is important to diversity and resistance to pests and disease.
[6] Yield per acre for switchgrass and poplar comes from presentation made by Greg Roth, Penn State College of Agriculture, "Energy from Biomass & Waste Conference" September 2007. Yield for willow comes from Heller et al. (2003).

benefit in tCO_2e/acre/year. In the Scenarios analyzed here, each acre of switchgrass was assumed to achieve an overall GHG benefit of 0.9 tCO_2e/year. Each acre of SRWC, assuming an equal mix of willow and poplar, would achieve an intermediate benefit between the willow and the poplar estimates, for a total GHG benefit of 1.2 tCO_2e/year.

The net CO_2e benefit per acre of biomass crops calculated in this way are quite similar to the results of Adler et al. (2007), who considered all fuel usage, equipment use, harvesting and transport costs, and production emissions to quantify net GHG comparisons for biofuel feedstocks in PA, including corn, soybean, alfalfa, switchgrass, hybrid poplar, and reed canarygrass. Switchgrass and hybrid poplar were the most favorable of all of the crops considered by Adler et al. (2007): ethanol and biodiesel produced from these crops reduced life cycle GHG emissions by ~115% below the life cycle CO_2e emissions produced by gasoline and diesel. In their analysis, switchgrass produced a net GHG sink of around 0.8 tCO_2e/acre/year for biomass conversion to ethanol and around 1.6 tCO_2e/acre/year when used for biomass gasification for electricity generation.

Biomass yield is an important source of variation in these estimates: yield can change dramatically depending on species and site conditions. As yield increases the expected GHG benefit increases dramatically as well.

Land areas examined include abandoned minelands, brownfields, oil and gas well sites, marginal agricultural land, and riparian areas.

With 250,000 acres statewide,[7] abandoned mine land sites provide a potential opportunity for carbon sequestration and biomass feedstock production[8]. Restoring abandoned mine lands, however, can be challenging and expensive due to uneven terrain, soil compaction issues, and the legacy of their prior use. Further, these lands, while concentrated in certain portions of the Commonwealth, are geographically diffuse.

The 389 brownfields in the state of PA comprise roughly 2330 acres of land area.[9] Although many of these previously developed and then abandoned areas are remediated and used as commercial or industrial sites, they also offer potential space for C sequestration.

Oil and gas well sites also occupy small acre sites around the state, totaling 250 acres of land area annually.[10]

[7] From PA DEP information: http://www.depweb.state.pa.us/abandonedminerec/cwp/view.asp?a=1308&q=454835. Accessed October 2007.
[8] See http://www.biosolidsinstitute.com/ and Toffey, W., Flamino, E., et al. (2007) Demonstrating Deep Row Placement of Biosolids in Coal Mike Land Reclamation.
[9] From EPA: http://www.epa.gov/brownfields/bfwhere.htm. Accessed October 2007.
[10] Personal communication, Ronald Gilius with J. Quigley and J. Jenkins, CCS, October 2007.

Marginal agricultural land is restricted by various soil physical/chemical properties, or environmental factors, for crop production. Based on an analysis of the1992 USGS National Land Cover Dataset together with soil characteristics obtained from the NRCS STATSGO soil dataset, Niu and Duiker (2006) reported that marginal agricultural land area of in PA totaled 2.92 million acres, approximately 36% of all land area in the state. This land was placed in the "marginal agricultural land" category because of its combination of soil and land cover characteristics, and includes land with high water table, steep slopes (high erodability), shallow soils, stoniness, and low fertility.

For the analysis of riparian areas, projected acreage from the Tree Vitalize and CREP forest riparian establishment programs were combined. Their goals and methods include restoration of 1,000 acres of forests along streams and water protection areas, as well as installation of stream bank fencing to exclude livestock and allow for natural forest regeneration.

The quantification for this option seeks to analyze the possible opportunities for planting different types of vegetation on various types of underutilized land in PA. Scenarios were designed for practicality, and include a scaled usage of available land in each land use category (25%, 50%, 100%) for establishing one or a combination of the four vegetation types: typical PA forest cover, warm-season grasses, short-rotation woody crops, and/or riparian buffers. The analysis illustrates the potential benefits and costs of different options under various levels of implementation.

- **Forest management strategies to enhance carbon sequestration.** This option addresses the potential for increasing carbon stocks in forests through changes in management practices on existing public and private forestland. Examples are practices that increase tree density, enhance forest growth rates, alter rotation times, or decrease the chances of biomass loss from fires, pests, disease, or decay. Increasing the transfer of biomass to long-term storage in wood products can also increase net carbon sequestration, provided a balance is maintained such that enough biomass remains on site as residues to serve as nutrient inputs to the forest. Practices may include management of rotation length, density and ecosystem health, and sustainable use of wood products. In addition, encouraging regeneration of existing forests through stocking/planting and restoration practices (e.g., soil preparation, erosion control, etc.) can increase carbon stocks above baseline levels and ensure conditions that support forest growth, particularly after intense disturbances.

The first component of this option seeks to quantify the GHG benefits and the economic value of adding to the certified land base, assuming the development of appropriate policy tools. The second component of this option focuses on enhancing carbon storage in existing forests through restocking.

- **Part A: Sequester more carbon through sustainable forest management.**

Managed forests can sequester more carbon than unmanaged forests for a number of reasons. Commitment to sustainable forest management practices implies a consideration of maintaining the health and productivity of the forest while being conscious of adequate regeneration, control of interfering or invasive species, a sustained yield of forest products, and a commitment to keeping the forest as forest, among other management objectives/values. These activities are easily discerned when compared to an unmanaged forest, and should be acknowledged as human induced activities, or, a choice to proactively affect maintaining and adding to the forests carbon sequestering capabilities.

Forest managers have an understanding of the various stages of ecological development and forest stand dynamics. Trees sequester carbon at varying rates through these stages, and eventually reach a point where equal amounts of carbon are emitted through mortality and decay than is sequestered by in-growth. Harvesting at this time (again, a human activity) and successfully regenerating the forest to a more vigorous stage of growth and development can sequester additional carbon, while the wood from the action can be converted into products which provide long term storage in either durable products such as furniture or flooring, or as feedstocks for biofuel to offset fossil fuel emissions, both at measurable GHG savings. Unmanaged forests face the risk of unchecked disturbance from pests, fire, and severe weather throughout these stages of development where there is considerable risk of carbon loss and accompanying loss of productivity. [11]

Furthermore, land participating in a certified management program is eligible to generate offset credits[12].

- **Part B: Restock under-stocked land.** Forests that are not fully stocked do not grow as quickly as forests in fully stocked stands. This component seeks to quantify the costs and benefits of restocking timberland acreage that is currently in an under-stocked condition in PA. Since the most feasible approach for restocking (other than ensuring natural regeneration) involves harvesting under-stocked forest, then regenerate a fully stocked forest, through replanting or managed natural regeneration, the quantification assumes that forests targeted under this option will first be harvested. The targeted acreage is then assumed to be regenerated to fully stocked forest stands or plantations, such that C sequestration in these acres occurs at a rate consistent with average C sequestration in these fully stocked stands in PA. The overall GHG impact of this option in a given year is calculated as the difference between emissions due to harvest and cumulative C storage on replanted acreage in that year.
    - Scenario 1: Restock 100% of poorly-stocked land statewide by 2020
    - Scenario 2: Restock 100% of poorly-stocked and 50% of moderately-stocked land statewide by 2020
    - Scenario 3: Restock 100% of poorly- and moderately-stocked land by 2020

[11] Managed Forests in Climate Change Policy: Program Design Elements. Sampson, Ruddel & Smith. 2007.

[12] Chicago Climate Exchange (CCX) – Forestry Contracts - http://www.chicagoclimatex.com/content.jsf?id=242

Harvested volume is available for durable wood products. Using this assumption, the C in the under-stocked forest is assumed to be emitted in the year of harvest, except for that proportion expected to remain stored in long-term pools (such as durable wood products and in landfills) 100 years after harvest. Thus the difference between harvest emissions and long-term storage is the net C loss due to harvest. The biomass not stored in these long-term pools is emitted to the atmosphere, either with or without energy production. If the harvested biomass is used for biomass energy, there could be an additional GHG benefit due to fuel switching via reduced demand for fossil fuel. This potential benefit was not quantified, but see below for an analysis of the overall potential for biomass energy in PA, as well as methodology to quantify the C stored in durable wood products 100 years after harvest.

Costs associated with this option include the costs of harvesting target acreage as well as the costs of replanting. The cost of harvest for a poorly stocked stand is $21.34/ m3 of volume (Sohngen et al. 2007). This is a one-time cost incurred in the year of harvest. The cost of planting was estimated on a per acre basis at $680/ acre.[13] Planting costs are often higher in Pennsylvania than in the region overall, due to the high cost of deer exclusion. Planting is also a one-time cost incurred in the year of harvest. The cost savings associated with fuel switching if biomass is used for energy are not quantified in this option.

The benefits associated with revenue from harvested wood are included in this analysis as a revenue stream that offsets the cost of replanting. Levelized cost effectiveness is not estimated for this option, because the option results in a net C emission rather than avoided C emission or sequestration benefit.

The overall GHG impact of this option in a given year is calculated as the difference between emissions due to harvest and cumulative C storage on replanted acreage in that year. The negative numbers in Table 3-3 represent net emissions rather than net GHG benefit, because the one-time loss due to harvest in a given year exceeds the C sequestration on cumulative planted acreage in all years of this analysis (2008-2020).

- **Wood for heat and power generation. Wood for liquid fuel production.** Market and policy forces are driving the expanding use of forest biomass energy. Biomass can be used to generate renewable energy in the form of liquid fuels (such as cellulosic ethanol, which is close to being market-ready), or through direct combustion to generate electricity, heat, or steam. Carbon in forest biomass is considered biogenic under sustainable systems; carbon dioxide emissions from biomass energy combustion are replaced by future carbon sequestration. Expanded use of biomass energy in place of fossil fuels results in net emissions reductions by shifting from high to low carbon fuels (when sustainably managed), provided the full lifecycle of energy requirements for producing fuels does not exceed the energy content of the renewable resource. Expanded use of biomass energy can be promoted through increasing the amount of biomass produced and used for renewable energy, and providing incentives for the production and use of renewable energy supplies.

[13] Paul Roth, personal communication with J. Jenkins, October 2007.

Market forces will determine the availability of wood and the impact on competing uses and users. The Commonwealth's biomass resources and the potential sources of plantation biomass are diffused over a large patchwork landscape. Estimates of total biomass volume based on sustainability (discussed below) are likely to prove optimistic when accounting for management limitations and economic considerations (transportation, fuel costs, access, competing markets for low-value wood).

Sustainable biomass supply

Professor Charles D. Ray, PSU School of Forest Resources, has estimated that the volume of wood in Pennsylvania's forests that is in "under-utilized small diameter" stems and that is potentially available for sustainable harvest is about 6 million dry tons per year. This theoretical sustainable biomass harvest figure does not account for mechanical and economic constraints or ownership approval for access to such biomass. The estimate was the subject of considerable debate during the CMAG process as to whether the estimate overstated available sustainable supply. Availability (landowner willingness), accessibility issues (topography, road access), and market forces influence actual supply. - At a minimum, this estimate provides a starting point from which to identify and contextualize issues relating to biomass feedstock supply. The CMAG has utilized this estimate in developing the various scenarios that are presented for illustrative purposes below.

Central to the CMAG analysis is the imperative that biomass needs to be harvested sustainably--using practices which maintain forest health, regeneration, resiliency, and other forest values and functions. For example, a certain amount of tree residue must be left behind following harvest activities to provide wildlife habitat, reduce erosion and provide other ecological benefits. Complete removal of all biomass during harvesting activities will impair forest health and is not sustainable.

Sustainability is as important economically and it is environmentally; biomass energy investors will need to prove that feedstocks are available in sustainable amounts in order to obtain financing. In this instance, business certainty and environmental protection go hand in hand.

Wood based energy facility

- **Part A: Increase wood usage as fuel for locally scaled community energy projects to meet needs for heat, chilling, and power generation as is appropriate to sustaining the resource and supportive of community needs.** Currently, biomass plants using wood as a primary fuel generate about 320,000 MWH of electricity annually,[14] or about 0.22% of the total electricity used in PA in 2005.[15] Biomass can be co-fired with coal under certain circumstances as well, so a larger proportion of the PA electricity demand would likely be met if wood as a secondary fuel were included in the analysis of biomass use.

  A large group of locally financed small projects spread widely across the Commonwealth could capture the value of replacing high-cost fuel imports and gain carbon benefits while limiting transportation costs of the feedstock. This model has been shown to allow displacement of significant quantities of current or projected fossil carbon release from a broad range of users - including industry, public institutions, commercial offices, and multi-family buildings - through reduced electrically driven cooling and distributed generation of electricity through combined heat and power facilities.

  - Scenario 1: Increase wood utilization to 3 million tons/ year by 2020
  - Scenario 2: Increase wood utilization to 6 million tons/ year by 2020

  Under each scenario quantified under this option, a linear ramp up to the goal level between 2008 and 2020 was assumed. In 2020, Scenario 1 meets 6.7% of statewide electricity demand with biomass fuels, and Scenario 2 reaches 13.4% of statewide demand with biomass fuels.[16] The GHG benefit of this option was quantified as the avoided GHG emissions from fuel switching for electricity production, assuming that avoided fuels were equally divided between coal, natural gas, and oil. Costs associated with fuel switching were not quantified, but are likely to be minimal if biomass is used to co-fire existing coal-based plants. Additional costs might include costs of changes in harvest practices or transportation.

[14] Personal communication, J. Sherrick with J. Jenkins, October 2007.
[15] Total electricity demand in PA (2005) is 148,273 thousand MWH (Energy Information Administration).
[16] Baseline electricity demand data for 2020 taken from PA I&F (CCS, 2006).

Some additional perspective is gained by considering the ability of short rotation woody crops to meet demands for heat and power generation. Developers interested in biomass-fired electricity generation in PA have indicated that they use a factor of 1,000 acres/MW of generation in considering the potential of short rotation woody crops to supply biomass feedstocks.[17]

- **Part B: Increase wood usage for ethanol production.** Wood-based ethanol production is a developing technology; however, some gross calculations can be made about the immediate potential of the technology to offset a portion of the state's gasoline consumption. The US Energy Information Administration estimates that Pennsylvania currently uses about 5 billion gallons of gasoline every year. Ethanol contains about 2/3 the BTUs of gasoline[18]; that is, replacing gallons of gasoline with gallons of ethanol is not a 1:1 proposition from a strictly energy content standpoint. Using an average yield ratio of 75 gallons ethanol/ton of wood, the estimated 6 million tons of available low value wood would yield 450 million gals of ethanol. 450 million gallons of ethanol is energetically equivalent to 300 million gallons of gasoline (450M X .667). Thus, it offsets a little over 6% of current Pennsylvania gasoline usage.

  Looked at another way, currently, there are three cellulosic ethanol developers considering plant locations in PA[19] with varying feedstock needs. The total biomass needed per year for all three plants is 1581 thousand tons, or 1.58 million tons. This value (1.58 million tons for cellulosic ethanol plants currently considering PA) was included in the analysis as Scenario 1. Scenarios 2 and 3 discuss the implications of doubling and quadrupling this capacity, reaching 3.2 million tons/ year and 6.4 million tons/ year respectively, for production of cellulosic ethanol from wood feedstocks.

  Some additional perspective is gained by considering the ability of short rotation woody crops to meet the demands of bioenergy. A 25 million gallon cellulosic ethanol plant would need an estimated 325,000 tons of feedstock wood per year, based on available data from firms currently considering locating in PA. To satisfy that demand from a hybrid poplar plantation alone, which has an estimated yield of 5 tons/acre/yr[20], would require a 65,000 acre plantation.

  Clearly, a mix of feedstocks will be needed for large biomass users, with close-in plantations smoothing out the supply curve and moderating price/transport costs.

  - Scenario 1: All plants actively considering PA locations at full capacity by 2015

[17] Assumes 4 dry tons/acre/y of hybrid poplar; personal communication, J. Quigley, April, 2008.
[18] http://www.eere.energy.gov
[19] Personal communication, J. Quigley with J. Jenkins, CCS, October 2007.
[20] PSU College of Agriculture

- Scenario 2: Double the currently-permitted capacity by 2015
- Scenario 3: Quadruple the currently-permitted capacity by 2015

The GHG benefit of using cellulosic ethanol is the incremental benefit of substituting ethanol for fossil fuels. Emission factors for reformulated gasoline, starch- based ethanol, and cellulosic ethanol were taken from a General Motors/Argonne National Lab study.[21] These emission factors incorporate the GHG emissions during the entire life cycle of fuel production (e.g., for gasoline: extraction, transport, refining, distribution, and consumption; for ethanol: crop production, feedstock transport, processing, distribution, and consumption). In Scenario 1, cellulosic ethanol would replace 1.6% of PA 2005 gasoline demand. Scenarios 2 and 3 would meet 3.2% and 6.4% of 2005 fuel demand, respectively. It is important to note that the biomass feedstock estimate needed to achieve Scenario 3 – 6.4 million tons/ year – exceeds the highest currently available estimates of sustainable biomass availability in PA.

For this analysis, it was assumed that Scenario 1 would incur the full cost of three manufacturing plants, while additional plants built under Scenarios 2 and 3 would incur an incremental 50% and 100%, respectively, of the costs estimated under Scenario 1.

The data presented above strongly suggest that small-scale biomass operations like thermal combustion for single schools or businesses, or district heat and power production, may be more appropriate and more environmentally and economically sustainable in Pennsylvania than large-scale operations that require huge volumes of feedstock annually.

USFS Forest Biomass Map of PA 2007

[21] *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions,* General Motors, Argonne National Lab, and Air Improvement Resource, Inc., May 2005.

- **Wood products and processes.** Durable products made from wood prolong the length of time forest carbon is stored and not emitted to the atmosphere. Wood products disposed of in landfills may store carbon for long periods under conditions that minimize decomposition and when methane gas is captured from landfills (carbon originally stored in wood products becomes methane during decomposition). Maintaining a sustainable harvest rate and converting it into durable wood products pool increases carbon sequestration from forests. This can be achieved through improvements in production efficiency, product substitution, expanded product lifetimes, and other practices. In addition, increasing the efficiency of the manufacturing lifecycle for wood products enhances greenhouse gas benefits. For this analysis, three scenarios of harvest levels are presented (one from the USFS Timber Products Output (TPO), an estimate of current harvest levels., and one which estimates harvest levels for PA State Forests).
    - Scenario 1: Calculate 2006 estimate for level of statewide harvest (1.12 billion board feet/ yr) through 2020
    - Scenario 2: Calculate statewide wood harvest levels at 1.5 billion board feet/ yr through 2020
    - Scenario 3: Calculate the GHG impact of current harvest level of 80 million board feet/ yr on PA State Forest Land through 2020

To quantify C stored in long-term products, forest harvest is used as a starting point. The methodology calculates the proportion of harvested wood that is diverted to each of four pools after 100 years: wood in use (i.e., building materials, furniture), wood in landfills (i.e., products that were previously in use and have been discarded), wood burned for energy capture, and wood that has decayed or burned without energy capture. The wood that has not been burned or decayed (i.e., the wood in the "in use" or "landfill" pools) is assumed to remain stored 100 years after harvest.

The cost of producing durable wood products is dependent upon various factors, which makes a cost analysis difficult and uncertain. An increase in C sequestration in durable wood products can be approached from several angles including: production efficiency, product substitution, expanded product lifetimes, and other practices. In this analysis only an estimate of GHG savings was provided for scenarios that increase supply of high quality wood for the manufacture of durable wood products.

A cost analysis for this option depends upon how these harvest levels are met, i.e. through afforestation or more intensive management of existing forest resources. Additional costs might include development of marketing materials and program administration meant to promote the use of durable wood products. These costs are not currently included in the analysis.

- **Urban and suburban forests.** Carbon stocks in trees and soils in urban land uses, such as in parks, along roadways, and in residential settings, can be enhanced in a number of ways, including retaining existing trees and forested areas, planting additional trees, reducing mortality and increasing growth of existing trees, and avoiding tree removal (or deforestation). Proper design, protection, and maintenance of urban and suburban forest canopy and cover would not only result in increased carbon storage, but could also reduce residential, commercial and institutional energy use for heating and cooling via a natural cooling effect.

- Scenario 1: Increment existing tree cover in PA urban and suburban forests by 10% by 2020
- Scenario 2: Increment existing tree cover by 25% by 2020
- Scenario 3: Increment existing tree cover by 50% by 2020

Currently PA contains 139 million urban trees. This option seeks to increment this total by 10%, 25% or 50%. Thus this option seeks to add 13.9, 34.8, and 69.5 million trees total by 2020 for Scenarios 1, 2, and 3 respectively. The number of trees planted each year is constant, with the target increment reached by 2020. C sequestration for each tree planted is calculated as 0.006 t C per tree per year. Offsets from avoided fossil fuel use for heating and cooling are the sum of three different types of savings: avoided emissions from reduced cooling demand, avoided emissions from reduced demand for heating due to wind reduction (this benefit is only applicable for evergreen trees), and enhanced fossil fuel emissions needed for heat due to wintertime shading.

Net cost for this option was found as the difference between cost of planting + maintenance and economic benefit of tree planting, including reduced energy cost, provision of clean water, aesthetic enhancement, property value increase, etc. The average annualized cost per tree is estimated at $37.28, and includes planting, pruning, pest management, administration, removal, and infrastructure repair due to damage from trees. Average annual net cost savings of -$206.91 per tree is the average of all trees in the city, and includes benefits of energy savings, improved air quality, improved storm water quality, and improved aesthetics.

A look at the data for these scenarios shows not only enormous GHG benefits from increasing urban canopy cover – indeed, the data presented here indicates that more carbon can be offset by urban/suburban forest than by afforestation of all marginal agricultural land - but also a net profit due to reduced energy use. Even at its lowest level of implementation (10% increase in canopy cover) this option shows a GHG benefit of 8.373 MMT CO_2e and a savings of over $11 billion. At the highest level of implementation (50% canopy increase), these benefits quickly increase to 41.9 MMT CO_2e and over $56 billion.

In order for each of the potential mitigation options to be considered seriously as real offsets, each needs to be understood in the context of their potential for permanence and leakage as well as in the requirements for accurate quantification and verification and ongoing monitoring. The significant challenge here is that the cost of these activities in their net sum cannot exceed the potential GHG benefit (or perhaps the sum of carbon offset credit value) or the endeavor will not be cost effective. Thus, the rules of the carbon game as defined by registries and trading regimes will shape the future role of the mitigation options reviewed here. For more information, see the registry section of this report.

Table 3-1. Summary Results for Afforestation in Different Vegetation Types on Various Land Use Types in PA

Land Use Category	Total Acreage Available for Policy Implementation			Vegetation Type	Cumulative GHG benefit, 2008–2020 ($MMtCO_2e$)			Net Present Value 2008–2020 ($ million)			Levelized Cost-Effectiveness ($\$/tCO_2e$)
	25%	50%	100%		25%	50%	100%	25%	50%	100%	
Abandoned Minelands	62,500	125,000	250,000	Afforestation with typical PA forest cover	2.197	4.395	8.791	$158.1	$316.2	$632.5	$71.94
				Short-rotation woody crops (willow and poplar)	2.002	4.005	8.010	$239.3	$478.6	$957.1	$119.51
				Warm-season grass production (switchgrass)	1.535	3.070	6.140	$239.6	$479.3	$958.6	$102.11
Brownfields	582	1,165	2,330	Afforestation with typical PA forest cover	0.020	0.041	0.082	$0.4	$0.7	$1.5	$18.00
				Short-rotation woody crops (willow and poplar)	0.019	0.037	0.075	$1.1	$2.2	$4.5	$60.30
				Warm-season grass production (switchgrass)	0.014	0.029	0.057	$0.4	$0.7	$1.4	$24.87
Oil and Gas Well Sites	813	1,625	3,250	Afforestation with typical PA forest cover	0.029	0.057	0.114	$0.5	$1.0	$2.1	$18.0

Marginal Agricultural Land	728,961	1,457,922	2,915,844	Afforestation with typical PA forest cover	25.63	51.27	102.53	$461.4	$922.8	$1,845.8	$18.00
				Short-rotation woody crops (willow and poplar)	23.36	46.71	93.42	$1,408.2	$2,816.3	$5,632.7	$60.30
				Warm-season grass production (switchgrass)	17.90	35.81	71.62	$445.3	$890.7	$1,781.4	$24.87

Table 3-2. Economic Costs of Site Preparation, Vegetation Establishment, Maintenance, and Monitoring for Vegetation Planting Scenarios in Option F-2

Land Use Type	One-Time Costs		Annual Costs	
	Site Preparation	Planting	Maintenance	Monitoring[22]
Abandoned minelands[23]				
Switchgrass[24]	$2,500.00	$1,281.88	$210.02	$29.00
SRWC[25]	$2,500.00	$1,000.00	$261.54	$29.00
Afforestation[26]	$2,500.00	$680.00		$29.00
Oil & gas well sites				
Switchgrass		$1,281.88	$210.02	$29.00
SRWC		$1,000.00	$261.54	$29.00
Afforestation		$680.00		$29.00
Marginal agricultural land				
Switchgrass		$1,281.88	$210.02	$29.00
SRWC		$1,000.00	$261.54	$29.00
Afforestation		$680.00		$29.00
Brownfields				
Afforestation		$680.00		$29.00
Riparian areas				
Afforestation		$680.00		$29.00

[22] Monitoring costs are assumed to be $29/acre for all vegetation types, assuming 20-year project duration (Walker et al., 2007).

[23] Cost of site preparation is average for abandoned minelands in PA, and includes site preparation with minimal compaction, establishment of an erosion barrier, and herbicide application (Kant and Kreps 2004).

[24] One-time planting cost and ongoing maintenance cost for switchgrass from Duffy and Nanhou (2002), who measured the cost of switchgrass production in Iowa at $518.75/ha. This work estimates switchgrass production costs using producers' data as much as possible and incorporating their actual management techniques, including costs of planting, management, harvesting, and any inputs.

[25] One-time planting cost for SRWC is estimated to be slightly higher than the one-time planting cost for typical PA forest due to specialized planting requirements and equipment. Ongoing maintenance cost is calculated from estimate of $43–$52 per tons of willow delivered (Volk, SUNY-ESF Willow Biomass Project), assuming average production yield of 13.6 tons/ha.

[26] Cost of afforestation is per acre cost of planting $150, plus tree ($100), herbicide ($130), and fencing ($300) costs (Paul Roth, DCNR, personal communication).

Table 3-3. Summary List of Forestry Policy Recommendations.

Scenario	Mitigation Option	GHG Reductions ($MMTCO_2e$) 2010	2020	Total 2008-2020	Net Present Value 2008-2020 (Million $)	Cost Effectiveness ($/tCO2e)
F-2	**Afforestation and planting**					
	Abandoned Minelands *(Refer to Table 2)*					
	Brownfields *(Refer to Table 2)*					
	Oil and Gas Well Sites *(Refer to Table 2)*					
	Marginal Agricultural Land *(Refer to Table 2)*					
	Establishing Riparian Buffers	0.038	0.175	1.212	$21.90	$18.08
F-3	**Forest management strategies to enhance carbon sequestration**					
B	**Restock understocked land statewide**					
B1	Restock 100% of poorly-stocked land by 2020	-6.5[27]	-4.5	-73.9	$1,126.65	NA[28]
B2	Restock 100% of poorly-stocked and 50% of mod.-stocked land by 2020	-29.7	-23.7	-355.2	$4,435.37	NA
B3	Restock 100% of poorly- and moderately-stocked land by 2020	-53.0	-42.9	-636.5	$7,744.10	NA

[27] Numbers prefaced with a minus sign represent net emissions rather than net GHG benefit, because the one-time loss due to harvest in a given year exceeds the C sequestration on cumulative planted acreage in all years of this analysis (2008-2020).
[28] Cost effectiveness is not estimated for this option, because the option results in a net C emission rather than avoided C emission or sequestration benefit.

Scenario	Mitigation Option	GHG Reductions ($MMTCO_2e$) 2010	2020	Total 2008-2020	Net Present Value 2008-2020 (Million $)	Cost Effectiveness ($\$/tCO_2e$)
F-4	**Wood for heat and power generation / Wood for liquid fuel production**					
A	**Increase wood usage for heat and power generation**					
A1	Increase wood utilization to 3 mill. tons/ year by 2020	0.47	2.05	14.35	NA[29]	
A2	Increase wood utilization to 6 mill. tons/ year by 2020	0.95	4.1	28.71	NA	
B	**Increase wood usage for ethanol production**					
B1	All plants currently considering PA locations at full capacity by 2015	0.40	1.06	10.07	$38.00	$3.77
B2	Increase wood utilization to 3 million tons/ year by 2020	0.79	2.12	20.13	$57.00	$2.83
B3	Increase wood utilization to 6 million tons/ year by 2020	1.59	4.24	40.27	$75.90	$1.89
F-5	**Wood products and processes**					
1	2006 Statewide Harvest Levels Held Constant (1.1 billion board feet/yr)	0.73	0.73	10.97		
2	Statewide Harvest Levels increased to 1.5 billion board feet/yr by 2020	0.81	1.00	12.96		
3	Maintain current State Forest Land harvest (80 million board feet/yr through 2020	0.04	0.04	0.57		

[29] Costs associated with fuel switching were not quantified, but are likely to be minimal if biomass is used to co-fire existing coal-based plants. Additional costs might include costs of changes in harvest practices or transportation.

Scenario	Mitigation Option	GHG Reductions ($MMTCO_2e$) 2010	2020	Total 2008-2020	Net Present Value 2008-2020 (Million $)	Cost Effectiveness ($/$tCO_2e$)
F-6	**Urban and suburban forests**					
1	Add 10% to existing tree canopy cover	0.276	1.196	8.373	-$11,310[30]	-$1,350.75
2	Add 25% to existing tree canopy cover	0.690	2.990	20.933	-$28,276	-$1,350.75
3	Add 50% to existing tree canopy cover	1.380	5.981	41.867	-$56,552	-$1,350.75

[30] Negative net economic costs indicate a net savings, as economic benefits outweigh costs of planting urban trees.

Chapter 4
Land Conservation

Recommendations in this chapter address the goal of estimating the carbon value of promoting the conservation of forested landscapes, with their associated carbon stocks and sequestration potential, as a means to mitigate net CO_2 release. Land conservation options include protection and acquisition of existing private forestland and/or lowering the statewide rate of private forestland conversion to developed uses.

The Potential for Land Conservation in Pennsylvania

Statewide Land Use

According to the 2003 *Brookings Institute Report: Back to Prosperity – A Competitive Agenda for Renewing Pennsylvania*, "Rampant land conversion is a first consequence of the way Pennsylvania is growing…Overall, Pennsylvania developed some 1.14 million acres, or 1800 square miles, of fields, open space, and natural land between 1982 and 1997 – the sixth largest such conversion after Texas, Florida, Georgia, North Carolina, and California. This also means that fully one-third of all the land that the Commonwealth has ever urbanized since its founding was developed in just 15 recent years. Put another way, over those 15 years the state converted land to low-density developed use at a rate equivalent to 209 acres a day, or 9 acres an hour, every hour. The 47-percent increase in Pennsylvania's urbanized footprint registered between 1982 and 1997 took place at a time when the population grew just 2.5%. Overall, the state developed nearly 4 acres of land for every new resident between 1982 and 1997, versus the national average of 0.60 acres per new resident. This means that Pennsylvania – one of the slowest growing states in the nation – converted more land per person than every other state except Wyoming."[1]

Losing Forestland

In Pennsylvania, the Natural Resources Inventory (NRI) estimated roughly 15.5 million acres of forest in 1997. Between 1982 and 1997, 902,900 acres of forest were converted to non-forest use (61,393 acres annually). Of this total, 597,900 acres were converted to developed use, for a net annual loss of 39,860 forested acres to development statewide. In this analysis, a baseline conversion rate of 39,860 acres of forested acres per year was used, representing the rate at which forestland was lost to development annually between 1982 and 1997.

[1] 2003, *Back to Prosperity – A Competitive Agenda for Renewing Pennsylvania*. The Brookings Institution Center on Urban and Metropolitan Policy; 120pp.

In each land conservation option presented, three scenarios were analyzed to estimate carbon savings. Basic assumptions used in all scenarios include: 50% of preserved forests are assumed to be Oak-Hickory and 50% are assumed to be Maple-Beech-Birch because they are the predominant forest types in the Commonwealth, each making up about 44% of total forest cover (FIA).

Carbon Savings and Economics

Total carbon savings in these scenarios were estimated from two sources: (1) the amount of carbon that would be saved as a result of preventing forest conversion to developed uses (i.e., "avoided emissions"); and (2) the amount of annual carbon sequestration potential that would be maintained by continued protection of the forest area.

Conversion of forests to developed use results in a one-time surge of carbon emissions, as well as forgoes future sequestration capacity. In this case, it was assumed that 53% of carbon stocks in biomass and 35% of carbon stocks in soils would be lost in the event of forest conversion, with no appreciable carbon sequestration in soils or biomass following development. The biomass loss assumption is based on research that shows heavy levels of individual tree removal results in the harvesting of 53% of carbon in aboveground biomass (Strong 1997). The soil carbon loss assumption is based on a study that shows about a 35% loss of soil carbon when woodlots are converted to developed uses (Austin, 2007).

Forests not converted in a given year continue to sequester carbon each year they remain in a forested use. Thus the carbon sequestration in forestland that is not converted is calculated as annual sequestration in cumulative protected acreage. Because acres protected in one year continue to store carbon in subsequent years, annual benefits of forest protection tend to accrue in later years of policy implementation.

Total costs of land acquisition under each scenario in LP-1, Forest Acquisition and Protection, were estimated using a per acre estimate of $1750, based on DCNR's Growing Greener II total land conservation program budget of $35M for protecting a goal of 20,000 acres. Costs were assumed to be one-time costs applied in the year that land is acquired. Maintenance costs are assumed to be zero. The analysis does not take into account potential cost savings, e.g., avoided land clearing costs and revenue from forest products on working forestlands that are protected under this policy.

The economic cost of avoiding conversion in LP-2, Reduce Forest Conversion to Developed Use, was calculated as the cost of acquiring conservation easements on private land. This is a one-time cost per acre of protected land and is estimated at $1500 per acre (Ramsey, personal communication).

A look across the data for all options and scenarios (Table 4-1) shows that while acquiring and protecting as much forest as possible generally has the greatest GHG benefit, these carbon savings depend greatly on the actual amount of forest that would have been lost to development, as enormous amounts of carbon are released during that conversion. The key to increasing carbon savings in both options is to avoid development of forested areas and the resulting release of carbon during the land conversion. Whether the development is avoided by purchasing the land or through the purchase of conservation easements on private forestland is the main influence on overall cost effectiveness. A two-prong strategy, of purchasing land in areas where full-scale development is most likely and working with private land owners to ensure forest conservation in areas where development is less likely, may well be the most cost effective approach to achieve desired carbon savings through land conservation.

If both options are undertaken at the lowest levels of implementation -- acquiring 20,000 acres of forest per year between 2008 and 2011 (LP-1) and reducing the net rate of forest conversion by 25% by 2020 (LP-2) -- the GHG savings between 2008 and 2020 are estimated to be 15.7 MMtCO2e. If both options are undertaken at the highest levels of implementation between 2008 and 2020, the GHG benefits increase to 69.6 MMtCO2e. Whether the land would have otherwise been converted to forest ("development threat") is an important variable in this analysis, as illustrated by the six scenarios described in Option LP-1. Specifically, if one assumes that 100% of the acquired land would have otherwise been developed, then avoided emissions on 100% of the protected forest can be calculated as a benefit of policy implementation. If only 50% of the converted land would have been developed without policy implementation, then avoided emissions can be quantified as a benefit on only half of the protected forest. Since the largest emission is from the one-time surge of emissions due to conversion, this assumption is critical.

Scenarios

- **Forest Acquisition and Protection.** This option seeks to protect existing forestland and its associated carbon stocks and sequestration potential through land acquisition by DCNR. When forests are converted to other land uses, forest biomass is typically cleared and the carbon stored in that biomass is emitted through decay and combustion, and/or is transferred into wood products. Non-forested areas generally contain much lower amounts of biomass and associated carbon, and sequester less carbon on a per area basis than forests.

Three alternative scenarios were analyzed for this option. Scenario 1 is based on full implementation of DCNR's Growing Greener II land conservation program, and Scenarios 2 and 3 are based on expansion of the program.

  - Scenario 1: Acquire 20,000 acres/year during 2008-2011.
  - Scenario 2: Acquire 20,000 acres/year every year during 2008-2020.
  - Scenario 3: Acquire 20,000 acres/year during 2008-2011, increase to 40,000 acres/year during 2012-2020.

Each scenario was calculated under four sets of assumptions regarding the threat level for development of PA forestlands, varying from 10% to 100% of land acquired under the program would have been developed if the program did not exist. Actual experience shows considerable variability; indeed, in many cases of DCNR acquisitions - for example, purchases of in-holdings or buffers for remote sections of state forest - land acquired is at zero threat of conversion. Thus, the scenarios are presented for illustrative purposes only. Projected total carbon savings was calculated taking into account both the one-time avoided emissions of carbon, which would have been released during land development, as well as the annual sequestration potential in the protected forests.

Under all scenarios and assumptions, the majority of carbon savings result from avoiding emissions that would otherwise be generated by conversion. As might be expected, as more land is purchased and protected from development, carbon savings go up; the option also becomes more cost effective. This option is significantly more cost effective and the carbon savings are much greater in all scenarios where it is assumed that 100% of the land would otherwise have been developed.

- **Reduce Forest Conversion to Developed Use.** This option seeks to reduce the rate of forest conversion, specifically targeting private forestland in order to reduce the rate of statewide forest conversion to developed uses. Forests store significant amounts of carbon. Conversion of forests to other land uses releases that carbon to the atmosphere. Initiatives that protect forestland reduce carbon emissions to the atmosphere in two ways: a) avoided deforestation reduces the amount of carbon that would otherwise have been released to the atmosphere, and b) carbon sequestration in protected acreage sequesters additional carbon.

Five alternative scenarios are analyzed for this option. In each scenario, the policy option is implemented linearly and gradually, with more acres protected each year. Full implementation is achieved by 2020 for all scenarios.

- Scenario 1: Reduce the net rate of forest conversion by 25% by 2020.
- Scenario 2: Reduce the net rate of forest conversion by 50% by 2020.
- Scenario 3: Reduce the net rate of forest conversion to zero by 2020.
- Scenario 4: Same as Scenario 2, but assume conversion threat of 20% (i.e. 5 acres are protected for each acre that is not developed)
- Scenario 5: Same as Scenario 2, but assume conversion threat of 10% (i.e. 10 acres are protected for each acre that is not developed)

GHG benefits from this option were estimated from two sources: (1) the amount of carbon that would be lost as a result of forest conversion to developed uses (i.e., "avoided emissions"); and (2) the amount of annual carbon sequestration potential that is maintained by protecting the forest area. The relative impact of avoided one-time emissions due to reduced forest conversion is nearly ten times the impact of cumulative sequestration in protected acreage for all scenarios.

The (non-discounted) economic costs of the alternative scenarios analyzed – ranging from $244 million to almost $1 billion – illustrate the stark fiscal challenge of pursuing a more aggressive DCNR land acquisition strategy.

Providing private landowners with technical assistance to guide forestland planning, encouraging responsible maintenance of private working forests through local ordinances, and providing tax incentives for forest conservation are all cost effective strategies for reducing forestland development. Purchase of conservation easements provides even greater long-term security. In areas where the threat of full-scale development is relatively low, this is a viable alternative to direct DCNR land acquisition. There is a possibility that Federal cap and trade legislation may contain provisions for additional conservation funding, such as for mitigation/adaptation activities.

Table 4-1. Summary List of Landscape Conservation Options.

Scenario	Mitigation Option	GHG Reductions ($MMtCO_2e$)			Net Present Value 2008-2020 (Million $)	Cost Effectiveness ($/tCO2e)
		2010	2020	Total 2008-2020		
LP-1	**Forest Acquisition and Protection**					
1A	20,000 acres/year 2008-2011, 100% development threat	3.32	0.18	14.78	260.6	17.63
1B	20,000 acres/year 2008-2011, 50% development threat	1.73	0.18	8.41	260.6	30.98
1C	20,000 acres/year 2008-2011, 20% development threat	0.77	0.18	4.59	260.6	56.79
1D	20,000 acres/year 2008-2011, 10% development threat	0.45	0.18	3.32	260.6	78.61
2A	20,000 acres/year 2008-2011, 20,000 acres/year 2012-2020, 100% development threat	3.32	3.76	45.45	690.4	15.19
2B	20,000 acres/year 2008-2011, 20,000 acres/year 2012-2020, 50% development threat	1.73	2.17	24.74	690.4	27.91
2C	20,000 acres/year 2008-2011, 20,000 acres/year 2012-2020, 20% development threat	0.77	1.21	12.32	690.4	56.04
2D	20,000 acres/year 2008-2011, 20,000 acres/year 2012-2020, 10% development threat	0.45	0.90	8.18	690.4	84.41

Scenario	Mitigation Option	GHG Reductions ($MMtCO_2e$)			Net Present Value 2008-2020 (Million $)	Cost Effectiveness ($/tCO2e)
		2010	2020	Total 2008-2020		
3A	20,000 acres/year 2008-2011, 40,000 acres/year 2012-2020, 100% development threat	3.32	7.35	76.11	1,120.2	14.72
3B	20,000 acres/year 2008-2011, 40,000 acres/year 2012-2020, 50% development threat	1.73	4.16	41.07	1,120.2	27.27
3C	20,000 acres/year 2008-2011, 40,000 acres/year 2012-2020, 20% development threat	0.77	2.25	20.05	1,120.2	55.87
3D	20,000 acres/year 2008-2011, 40,000 acres/year 2012-2020, 10% development threat	0.45	1.61	13.04	1,120.2	85.89
LP-2	**Reduce Forest Conversion to Developed Use**					
1	Reduce the net rate of forest conversion by 25% by 2020	0.4	1.7	11.9	167.3	14.08
2	Reduce the net rate of forest conversion by 50% by 2020	0.8	3.5	23.8	334.5	14.08
3	Reduce the net rate of forest conversion to zero by 2020	1.5	7.0	47.5	669.1	14.08
4	Same as Scenario 2, but assume 20% development threat	0.2	0.9	6.0	334.5	55.84
5	Same as Scenario 2, but assume 10% development threat	0.1	0.6	3.8	334.5	88.75

Chapter 5
Registries

In anticipation of a GHG cap-and-trade system or other mandatory GHG policies, there have been federal, state, and private efforts to establish GHG registries, i.e., standardized and transparent accounting practices that measure emissions and/or sequestration by governments, businesses, or other entities. Protocols for registries need to include not only accounting and reporting requirements, but also quantification standards and verification procedures. The CMAG focused considerable attention on registry designs and their suitability for application to geologic and terrestrial sequestration, and how those designs could encourage the fullest utilization of the state's sequestration resources. It was the CMAG's intent to identify policy guidance that would encourage maximum possible participation in carbon markets by owners of the Commonwealth's terrestrial and geologic sequestration resources.

During the course of the CMAG process, negotiations among many states concluded and resulted in the creation of the Climate Registry,[1] a merger of several state and regional efforts to establish a truly national system aimed at developing and managing a common greenhouse gas emissions reporting system. It will be capable of supporting various greenhouse gas emission reporting and reduction policies for its member states and tribes and reporting entities. It will provide an accurate, complete, consistent, transparent and verified set of greenhouse gas emissions data from reporting entities, supported by a robust accounting and verification infrastructure. Thanks to the leadership of Governor Edward Rendell, Pennsylvania became a member of the Climate Registry, and can help shape it and ensure its success. The CMAG's registry recommendations are intended to support and guide Pennsylvania's participation in the Climate Registry, and in other relevant efforts such as the federal Department of Energy 1605(b) Registry.[2]

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Background

In developing the CMAG registry design guidance, the CMAG focused on key state-level forestry and geologic resource policy needs that include:

- The mandate by Governor Rendell to Pennsylvania state agencies to develop a comprehensive carbon management strategy for the state in 2007.
- The directive from DCNR Secretary Michael DiBerardinis to develop a carbon management strategy for DCNR.

[1] *See* http://theclimateregistry.org.
[2] *See* http://www.pi.energy.gov/enhancingGHGregistry/sitemap.html.

- The rapid growth in GHG policy proposals by the Pennsylvania General Assembly and the US Congress.
- Growing interest by Pennsylvania stakeholders in climate actions and public private partnership opportunities.
- The ability of forests and geologic formations to store carbon as well as act as a source of emissions, thereby requiring net full life cycle measurement of GHG gains and losses.
- The significant interplay between energy and land markets with forestry and geologic resources carbon management actions. [a little unclear]
- The diversity of methods by which forestry and geologic resources are and can be managed, including current practices as well as approaches that may be developed in the future, such as GHG emissions trading or other market based approaches.
- The diversity of and size of management entities involved in carbon management for forestry and geologic resources, including private landowners (both industrial and nonindustrial), and public landowners (including state and municipal). The role of state agencies as implementing parties, including DCNR's Bureaus of Forestry and Topographic and Geological Survey, and the Department of Environmental Protection.
- The diversity of scale for forestry and geologic options that range from single, localized projects, to aggregate statewide programs and policies.
- The rapidly evolving nature of GHG policy, markets and technology related to terrestrial and geologic carbon resources and sequestration.
- The existence of significant gaps and potential inconsistencies in current state and national registry protocols to address forestry and geologic policy and management needs at a comprehensive level.

The CMAG agreed on the following purposes for a registry:

- Support implementation of comprehensive statewide climate mitigation actions related to Forestry and Geologic resources.
- Establish quantitative implementation baselines for current and future state policies, programs and projects.
- Report and track progress of current and future state policies, programs and projects in terms of greenhouse gas emissions reductions made in implementing state mitigation actions.
- Enable reciprocal disclosure, recognition and reward of climate mitigation actions at the local, state and multi state level.

Design Parameters and Recommendations

Recommendations were developed on 16 key registry design parameters:

1. Voluntary or mandatory status
2. Greenhouse gases covered
3. Scope and scale of emissions/sinks covered
4. Organizational boundaries
5. Level of aggregation
6. Eligible sectors and sub-sector activities
7. Eligible implementation mechanisms
8. Timing of base year and baselines
9. Emissions measurement, verification & monitoring methods
10. Emission reductions measurement methods
11. Eligibility and rules for offsets, credits, baseline protection
12. Reporting & recordkeeping requirements
13. Cost and membership criteria
14. Geographic coverage and reciprocity
15. Time period and duration of actions
16. Incremental effects beyond baseline

The CMAG compared current registry designs at the state, regional and national level for each of the design criteria, and developed specific guidance for each criterion to support CMAG forestry and geologic resources options. The guidance appears in Table 5-1 below.

Table 5-1. Registry Design Recommendations

Registry Design Parameter	Registry Design Recommendation
1. Voluntary or Mandatory *Reporting* Requirements	• May need to cover both types of systems in the future, starting with voluntary approaches. • Flexibility mechanisms may be important.
2. Greenhouse Gases Covered	• Included, but not limited to, carbon dioxide, methane, nitrous oxide and black carbon are important to forestry and geologic resources. Black Carbon may be important in the future if/as it becomes officially included in GHG accounting.
3. Scope and Scale of Emissions/Sinks Covered (direct, indirect, minimum size, etc.)	• Small sources/sinks are important to forestry. • Should include carbon sequestration as well as carbon emissions. • Should include geologic sequestration (new treatment technologies). • De minimis reporting standards are essential and practical especially for voluntary reporting of small sources.
4. Organizational Boundaries (entity, facility, aggregated program, etc.)	• Aggregation is an important feature. Should allow for various entities to be aggregators, including state agency programs and or other aggregation mechanisms that serve landowners (see also #5 below). • Should cover landowners. • Should cover companies. • Encourage widespread participation (note that in PA participation will likely be voluntary), and consider reporting burden, particularly with respect to entity size (i.e., equal playing field for small private land owners and large industrial land owners).
5. Level of Source/Sink Aggregation	• Should cover small source/sink aggregation by programs and institutions related to forestry management programs. • Important to have clear rules and accounting of how to quantify best management practices and programs. • Should ensure that double-counting does not occur.
6. Eligible Sectors and Sub-sector Activities	• Should cover full range of CMAG policy, program and project recommendations, including: • Forestry

Registry Design Parameter	Registry Design Recommendation
	o Protection of existing carbon stocks o Management of pre harvest stocks for carbon gain o Management of post harvest stocks for carbon gain • Geologic o Carbon sequestration o Coal bed methane recovery
7. Eligible Implementation Mechanisms	• Should provide flexibility to cover a full range of methods used to implement carbon management options, including: o Voluntary and or Negotiated Agreements o Technical Assistance o Financial Incentives o Targeted Spending o Codes and or Standards o Market Based Approaches o Pilots and or Demos o Information and Education o Research and Development o Reporting and Disclosure
8. Timing of Base year and Baselines	• Should cover actions recommended by the CMAG from startup to conclusion of the action period, including base year and baseline methods. • A base year of 1990 is desirable given that certain forest and land preservation practices have been implemented since 1990 (such practices include sustainable forest certification, installation of cogeneration facilities, etc.). • The impact of the baseline year on other sectors should be taken into consideration also.
9. Emissions Measurement, and Emissions Reductions Verification & Monitoring Methods	• As needed to satisfy requirements of policy implementation mechanisms and reciprocal agreements. • Guidance should be tiered and flexible, providing recognition for sophisticated approaches. • Verifiers must be properly qualified for forestry, land conservation and geologic sequestration project verification.

Registry Design Parameter	Registry Design Recommendation
10. Emission Reductions Measurement Methods	• Full life cycle analysis of forestry and geologic resources actions • Net GHG impacts • Incremental impact analysis beyond baseline • Aggregate, statewide impacts of small source/sink actions
11. Eligibility and Rules for Recognition and Reward	• Determination of the value of the credits is outside the function of the Climate Registry. • State agencies and other organizations should be able to generate and trade credits. • Financial additionality should not be used as an eligibility requirement.
12. Reporting & Recordkeeping Requirements	• Reporting should include sources and sinks • Activities related to natural resources should be covered • Should require detailed and transparent reporting (general/cross-cutting).
13. Cost and membership criteria	• As needed.
14. Geographic coverage and reciprocity	• As needed to satisfy requirements of policy implementation mechanisms and reciprocal agreements.
15. Time period and duration of actions (permanence)	• Should include long term effects of carbon storage and release. • Registry must address credit allocation to ascribe to year in which credit is gained or lost (contemporaneous).
16. Incremental effects beyond baseline	• Need to recognize existing and planned actions. • Need to credit the preservation of existing forests. • New actions taken are actions that otherwise wouldn’t have been taken (beyond the reference case). • The action is not removing or converting the forest to some emission source and permanent non-sequestering status. • Need a referencing and forecasting system to project forest carbon fluxes.

These recommendations identify key design parameters that must be considered carefully if all of the owners of Pennsylvania's terrestrial and geologic sequestration resources are to be positioned favorably to participate in carbon markets. These recommendations should serve as critical guidance to the positions the Commonwealth advocates in its participation in the Climate Registry.

Appendix A
Geologic Sequestration in Pennsylvania: Land Ownership Issues

A paper by Ted Borawski of DCNR[1]

Introduction

The issue of subsurface ownership needs to be addressed early in the process of geological sequestration. The complications of land ownership and title in Pennsylvania are complex enough that excellent prospect areas for sequestration projects might be entirely unsuitable due to unresolved ownership issues. Obtaining ownership and CO_2 sequestration rights on private lands could be serious enough to degrade the long term objective of sequestration in Pennsylvania. It is possible that the cost of obtaining the mineral rights, potential access problems with pipeline right-of-ways, and potential liability issues could pose limitations to the large-scale application of sequestration technology. As such, as a last resort, the Commonwealth should consider the possible use of eminent domain to obtain the necessary rights to pave the way.

Land Ownership And Mineral Rights

Fee simple ownership is defined as ownership of land with no reservations. William Penn and his heirs acquired, surveyed, tracted, and sold the lands deeded to him by the Crown, fee simple (without any reservations), to private individuals beginning in 1682. The private owners that acquired lands fee simple were mostly unaware of the possibilities of exploitation of the mineral wealth in the near surface and deep subsurface. Indeed, the vast majority of landowners were farmers whose sole intention was farming their lands for a living.

As Pennsylvania was settled and the majority of its lands transferred to private ownership, the exploration of Pennsylvania for mineral wealth began with the discovery of large amounts of iron ore in the Cornwall region of eastern Pennsylvania in 1734. Soon after, coal was discovered in and around present day Pittsburgh. Since that time, Pennsylvania has had a long history of exploitation of its mineral wealth. This has been accomplished either by the original owner selling the rights to specific minerals (for example, coal and/or oil and gas) to a new owner by deed, or by leasing the mineral rights, with a limited set of rights to exploit the minerals, to an operator who would pay ongoing rentals and royalties to the owner.

Ownership is further complicated by the process known as “severance of rights,” which has been occurring in Pennsylvania since the early 1700’s. This involves severing mineral, wind, timber, and other rights from the original deed title. The major difference

[1] This paper benefited substantially from inputs and edits from John Harper, DCNR.

between a severed title right and lease rights, besides monetary payout factors, is that a lease is limited in term and will expire at some time in the future, whereas a titled right never passes away and may be titled to new owners in an unlimited fashion.

Once severed, the right to some or all subsurface resources can be passed on to successor generations through inheritance, sale, or trade by deed. Thus, the title chain is often unbroken from the time a right has been severed until today where many Pennsylvania landowners own only the surface and none of the subsurface rights. Leases against certain rights might last for generations, but eventually expire when the resource runs out or the economics of the situation no longer make sense and the lease agreement is terminated.

The start of the trend to sever subsurface rights began with the widespread commercial mining of coal in both western and eastern Pennsylvania in the 1800s. At that time, taxes were not assessed against subsurface coal rights, so severing the coal rights put some legal distance between the surface and subsurface owners should the surface owner go into forced sheriff's sale. The counties in Pennsylvania where the severance of subsurface rights and the widespread leasing of subsurface rights are commonly found are shown in Figure 1 and Table 1.

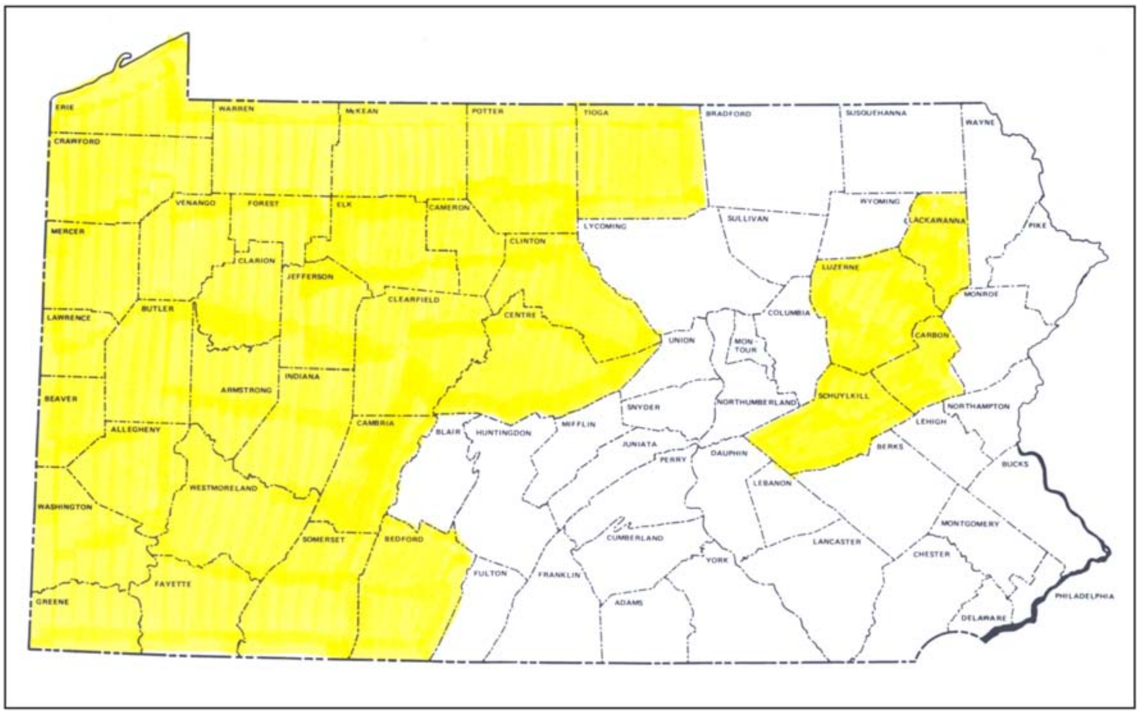

Figure 1. Map of Pennsylvania counties that have been widely affected by severance of subsurface rights from surface ownership.

The severed rights, especially in the oil and gas fields, might have been fractionated as inheritance practices caused division of the rights into smaller and smaller shares. For example, a 100 percent undivided share in the gas rights on a particular tract might have been subdivided into equal or unequal shares based on fractions. Fractional designations

Table 1. Pennsylvania counties affected by severed rights for oil, gas and coal. Names in italics indicate both the oil and gas and coal rights are often severed.

Oil & Gas Rights Reservations Common	**Coal Rights Reservations Common**
Allegheny	*Allegheny*
Armstrong	*Armstrong*
Beaver	*Beaver*
Bedford	*Butler*
Butler	*Cambria*
Cambria	*Cameron*
Cameron	Carbon
Centre	*Clarion*
Clarion	*Clearfield*
Clearfield	*Crawford*
Clinton	*Elk*
Crawford	*Fayette*
Elk	*Forest*
Erie	*Greene*
Fayette	*Indiana*
Forest	*Jefferson*
Greene	Lackawanna
Indiana	*Lawrence*
Jefferson	Luzerne
Lawrence	*McKean*
McKean	*Mercer*
Mercer	Northumberland
Potter	Schuykill
Somerset	*Somerset*
Tioga	*Tioga*
Venango	*Venango*
Warren	*Warren*
Washington	*Washington*
Westmoreland	*Westmoreland*

of 8ths, 16ths, 32nds, and 64ths are commonly found in deeds. These fractional rights might also be leased to different parties for exploration and development activity.

In the case of leasing, by state law a royalty of at least one eighth (1/8) of whatever is produced must be paid on leased rights for oil and gas, subject to the fractional ownership of the rights.

Gas Storage Rights And Carbon Sequestration

Pennsylvania today is capable of storing 1.2 trillion cubic feet of natural gas in operational gas storage reservoirs, accounting for a significant number of reservoirs that are unavailable for geological sequestration. Still, a much larger number of oil and/or gas reservoirs might be available for sequestration, assuming that primary production has ceased or can be purchased for a reasonable price, or the leases have expired and reverted to the owners. Although a large number of these reservoirs are above the depth where CO_2 will remain in the supercritical stage when injected, the potential storage capacity is enormous. Because many of them are readily available, close to emitter locations, and their geological and engineering characteristics are already well known, they should not be ignored. In the Unites States today there are no gas storage operations involving injection into brine filled reservoirs; therefore, these might be the best available reservoirs for carbon sequestration.

Gas storage rights, which can be bought or leased separately from mineral extraction rights, are defined by different companies in different ways. Most corporate legal staffs agree that, to actually own gas storage rights, you must have direct title to the pore space in the rock, or to the minerals that make up the rock. With ownership of the rock pore space, the produced gas or oil simply becomes the fluid currently residing in the space (when it is considered to be depleted, the pore space still has some residual fluid in place). Most oil and gas industry leases, as originally presented to the mineral rights owner, contain language that allows for gas storage to be conducted at the operator's discretion, and the landowner is compensated by rentals equal to the rentals paid for the primary lease. The Commonwealth, and many private landowners, will not cede gas storage rights in their primary gas leases, but keep the rights separate for later utilization if feasible. This means that the vast majority of gas storage rights in Pennsylvania currently are controlled by the lease operators for lands where the leases are still in effect. As a result of this, arrangements to secure the right to store CO_2 in the subsurface often will be subject to prior leasing agreements, where the right to store gases is in private hands.

For the owners or lease holders of the gas storage rights, storing CO_2 in depleted oil and gas reservoirs or in deep saline reservoirs might present a long-term financial gain with little risk. The owner of the gas storage rights at a sequestration site would receive rental payments, for all practical purposes, in perpetuity for the privilege of continuous CO_2 storage. The operator or lease owner probably would require the sequestering entity to assume all liability for leaks and other problems potentially associated with geological sequestration, and require full indemnification for the life of the project (hundreds to thousands of years?). It is unknown how the burden of hundreds of years of storage rental payments would affect the economics of CO_2 storage, but that factor must be taken into account prior to any project initiation.

Operators of producing oil and gas fields and gas storage fields might or might not be willing to sell or lease their reservoirs for carbon storage and forgo any potential future oil and gas production or gas storage opportunities. This will be purely a business decision that will take into account the anticipated value of carbon credits, possible future natural gas storage economics, and the perceived willingness of interested parties to pay at or above market rates for storage privileges.
In the long run, purchasing the gas storage rights in fee from the owner and purchasing the lease rights from the existing lease operator would reduce the long term cost of storage rentals. It is not clear what this might ultimately cost, but in the end it might be better to pay up front to control the situation and ensure the longevity of the project.

Another possibility would be to target state-owned lands where the state has fee simple ownership. Figure 2 illustrates the gross ownership of State Forest lands in Pennsylvania.

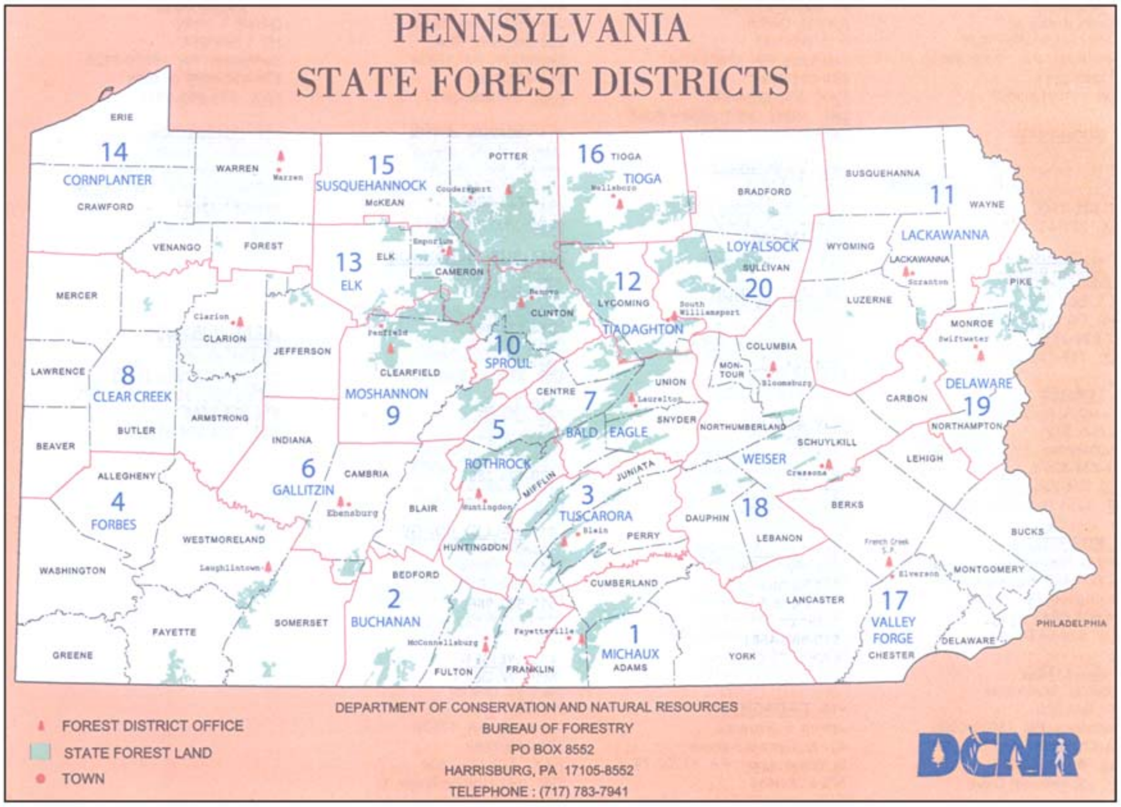

Figure 2. Pennsylvania State Forests and State Forest districts.

The Commonwealth owns approximately 85% of these lands fee simple. Although the vast majority of the State Forest lands are situated well away from population centers where most of the CO_2 is generated in large quantities, many are near future sites of ethanol plants and other manufacturing centers that will emit large quantities of CO_2. Also, it might be most desirable to limit the locations of CO_2 repositories to public lands where future land use could easily be restricted (the long term safeguards for the stored CO_2 includes limiting human activity that may breach the reservoir, allowing large volumes of gas to leak or vent to the surface, groundwater aquifers, and atmosphere). Such restrictions would not be as easy to accomplish on private lands.

Coal Ownership And Carbon Sequestration

Coal ownership and coal rights in Pennsylvania are similar to oil and gas rights. Although the Pennsylvania Supreme Court ruled in 1983 that coalbed methane (CBM) belonged to the coal owner or lessee of a severed title by “ownership-in-place,” this case did not resolve the ownership issue. Claims have been made on behalf of the oil and gas owner or lessee, the surface owner, the coal owner, and combinations of all of them. Despite the court ruling, it should not automatically be construed that a coal owner is the sole owner of the CBM. Instead, the language of the actual deed will determine who owns the

CBM.[2] This is critical when planning to use CO_2 sequestration to enhance CBM recovery. Also, the right to inject CO_2 into a coal seam would have to be acquired from the owner in some sort of storage agreement, probably similar to a gas storage agreement in a conventional reservoir. If the coal seam has never been exploited for its gas content the owner might demand payment for his gas up front, in addition to the storage fees. Alternatively, the storage operator might lease or buy the CBM rights and use the sequestered CO_2 for enhanced CBM recovery, with the lessee receiving rental and royalty from the production.

[2] Markowski, A. K., 2001, *Reconnaissance of the coal-bed methane resources of Pennsylvania*. Pennsylvania Geological Survey, 4th ser., Mineral Resource Report 95, 134 p.

Appendix B
An Approach to Geological Sequestration

A paper by John Harper[1], Ph.D., and John Quigley[2]

Table of Contents

List of Figures

[1] Chief of Subsurface Geology, Bureau of Topographic and Geologic Survey, DCNR
[2] Director of Legislation and Strategic Initiatives, DCNR

Overview: A Strategic Opportunity

Coal is abundant in Pennsylvania and globally, and it is cheap compared to other fuels. It will inevitably continue to be a major domestic and international energy source for decades to come, particularly as energy demand grows in rapidly developing countries like China and India. Continued reliance on coal in the face of global climate change will require the development of clean coal and carbon capture and storage (CCS) technologies, and the development and exploitation of geologic storage capacity. Without those developments in Pennsylvania, the high regional demand for the state's coal-based generation could shift to alternate supplies with the advent of Federal carbon constraints (likely by 2010), and there could be substantial electricity market disruptions.

Just as the Governor's alternative energy policies have attracted investment and jobs to Pennsylvania, there are similar economic opportunities for first-actors in controlling the greenhouse gas (GHG) emissions from the mining, combustion, and liquefaction of coal. There will be significant opportunities in manufacturing the specialized CCS equipment that will be needed for both retrofitting of existing coal-fired plants and new construction, as well as in producing methane in advance of mining (rather than venting it to the atmosphere). If those technologies can be developed in the Commonwealth, substantial exports should follow, including to the giant economies of China and India, which will face international pressure to moderate their GHG emissions.

The Commonwealth has a significant potential competitive advantage in its geological sequestration capacity - estimated at equivalent to more than 250 years of emissions at present rates. However, that capacity must be proven on a site-by-site basis. To enable sustainable economic growth in a carbon-constrained world, Pennsylvania should prepare now and, as a first step, inventory its geological sequestration resources and comprehensively map all of the state's geological reservoirs.

The Commonwealth's geological storage capacity must then be proven. That process can be the springboard to approaching climate change as an economic opportunity for Pennsylvania. While there is significant domestic and global experience with carbon capture technologies and for injecting large amounts of gas, including carbon dioxide (CO_2), into geological formations, there are no major CCS projects currently underway to demonstrate the integration of available technologies with coal-fired power plants. The 2007 Federal energy bill provides for $240 million/year through 2012 for CCS demonstration and an additional $30 million/year for geological assessments. If and when those funds are appropriated, states that move quickly and opportunistically to at-scale pilot projects will be best positioned to leverage Federal investment and capture market leadership in both regional energy generation and technology development. No state has moved to a leadership position in plant-level scale-up, but many want to. Pennsylvania has an opportunity to once again assert national leadership in advanced energy development.

This paper proposes an approach to inventorying the Commonwealth's geological sequestration capacity and to pursuing an at-scale pilot CCS project.

Requirements for Siting Geological Sequestration Projects in Pennsylvania

DCNR has identified a two-step approach to assessing and testing Pennsylvania's geological sequestration resources in order to prove their location, extent, capacity, reliability, and safety.

Step One: Basic Geological Assessment for Central and Eastern Pennsylvania

The geological characteristics of western Pennsylvania are well known as a result of 150 years of drilling for oil and natural gas; however, those of central and eastern Pennsylvania are not, and must be assessed for the Commonwealth to have a full picture of storage resource potential. The first step consists of performing literature/file searches for pertinent geological and engineering data on the characteristics of the rocks in the subsurface, and mapping out known reservoirs in the central and eastern part of Pennsylvania, as a precursor to performing basic seismic surveys in site-specific areas. The resulting inventory of candidate sites/regions could be mapped and made available to industry.

The estimated cost of this step is a minimum of $600,000 if done within DCNR (Bureau of Topographic and Geologic Survey) and significantly more if done by an outside contractor.

Step 2: A Pilot Geological Sequestration Project

In tandem with or following a preliminary statewide assessment, a geological sequestration pilot project is recommended. The subsurface geology of western and north-central Pennsylvania presents the best candidate sites for an initial pilot. The specific location of a potential geological sequestration project will depend on a variety of factors, including the location of the source of the CO_2, land ownership, the target subsurface formation, and the quality of available geological and engineering data for the target formation. The minimum cost to the Commonwealth for the preliminary engineering to obtain sufficient data to determine if one or more geological formations have the capability of accepting and storing CO_2 in large quantities alone would be $335,000.

Once a site has been selected, DCNR has identified 3 alternatives for a geological sequestration pilot:

1. A full-spectrum, at-scale CCS pilot project with CO_2 separated from flue gas and captured at a coal-fired power plant. This has a preliminary project budget of $40 million over a four-year injection period, with additional funding for 6 years of monitoring.

2. A pilot focusing solely on proving geological sequestration capacity and safety. This approach requires that CO_2 be purchased from an industry that produces an almost pure stream of the gas, such as an ethanol or gas processing plant. Estimated minimum cost for a meaningful test of about 1 million tons of CO_2 injected is $15 million.

3. A third alternative would be to evaluate purchase of truckloads/tanker cars of liquid CO_2 from a commercial source of the gas, such as a food-grade or industrial supplier. The

current cost for food-grade CO_2 is about $100 per ton, which would make the total cost of a large-scale project (one million tons or more) cost prohibitive.

Risks Associated with CO_2 in Geological Reservoirs

Many types of risk associated with sequestering CO_2 in geological reservoirs can occur, but the primary ones include:

- CO_2 and methane (CH_4) leakage out of the reservoir through faults and fractures, or through unplugged or improperly plugged wells
- Seismic events (earthquakes) associated with fault slippage or stressed caprock
- ground movement, particularly surface uplift resulting from overpressuring the reservoir
- contamination of groundwater supplies
- displacement of brine into non-saline aquifers.

Other Issues

Other issues will need to be resolved before a sequestration project can begin:

- Storage (mineral) rights ownership
- Transportation, particularly as related to pipeline infrastructure
- Operational requirements/regulation
- Measuring, monitoring, and verification options, and assurance of safety at the site.
- Liability
- Public outreach, education, and acceptance

The U. S. Environmental Protection Agency (EPA) has announced plans to develop regulations governing geological sequestration by the summer of 2008.

An Approach to Geological Sequestration

Introduction

In an effort to identify and understand the potential competitive advantages that the Commonwealth may possess if and when carbon emissions are limited or regulated, the Pennsylvania Department of Conservation and Natural Resources (DCNR) has been investigating the potential for carbon sequestration in both terrestrial and underground geological environments within the state, and particularly where state-owned lands can be best used for storage. This storage capacity represents a new natural resource whose development and management will be crucial to the continued growth of the state's economy in a carbon-constrained world.

A Strategic Opportunity for Pennsylvania

Coal is abundant in Pennsylvania as well as globally, and it is cheap compared to other fuels. It will inevitably continue to be a major domestic and international energy source for decades to come, particularly as energy demand grows in rapidly developing countries like China and India. It may also become a major feedstock for conversion into liquid transportation and gaseous fuels. However, the emissions from combustion (and future processing) of coal, and venting of methane from coal seams (which is still occurring in Pennsylvania despite the increasing market for coalbed methane) are the most serious contributors to global warming. Controlling the climate consequences of continued reliance on coal at sustainable costs will require the development of new technology.

The Commonwealth's policy response to climate change does not have to impose a drain on the state's economy; indeed, it can be a potential boost. Just as the Governor's alternative energy policies have attracted investment and jobs to Pennsylvania, there are similar economic opportunities for first-actors in controlling the greenhouse gas (GHG) emissions from the mining, combustion, and liquefaction of coal. While regulation is clearly part of the solution, so is innovation. To extend the national leadership that the Governor has demonstrated on alternative energy to climate change policy - and to reap similar economic development benefits – the Commonwealth must develop practical policies that go beyond passively awaiting a technological miracle. The Commonwealth should approach climate change as an economic opportunity.

There will be winners in the confrontation with global warming. Pennsylvania can position itself to win by turning the assumed costs of GHG control into sources of economic growth and good jobs. Once the technology is developed, there will be significant opportunities in manufacturing the specialized equipment needed for both retrofitting of existing coal-fired plants and new construction, and in manufacturing the technologies that will allow the production of methane in advance of mining, rather than venting it to the atmosphere. Well-paying, skilled jobs can be grown in Pennsylvania if the Commonwealth becomes a leader in driving this technology.

Indeed, substantial export opportunities should follow, including to the giant economies of China and India, which will face international pressure to moderate their GHG emissions.

Pennsylvania must begin to position itself as a center of both technology development and production. The opportunities for Pennsylvania begin with exploiting the Commonwealth's suitability as a natural laboratory for demonstration of geological sequestration – the essential foundation on which continued reliance on coal must be built. Pennsylvania must develop strategies to exploit its large potential storage resources in a way that would, at the same time, establish the Commonwealth as a prime location for other carbon capture research and development, demonstration, manufacturing, and, eventually, export programs.

While the federal government has invested – and will likely continue to invest at some presently unknown level – in seven regional partnerships like the Midwest Region Carbon Sequestration Partnership (MRCSP), the genuine research needs that are necessary to move geological sequestration toward commercial acceptance and viability merit a more concerted effort than presently exists. Indeed, the 2007 Federal energy bill provides for $240 million/year through 2012 for CCS demonstration and an additional $30 million/year for geological assessments. Even if/when those funds are appropriated, there is a role for state action and state leadership.

Comprehensive mapping of all of Pennsylvania's geological sinks is needed as a first step towards leadership in CCS technology development. To rely on funding and timescales of the federally-funded regional partnerships to amass the data that will be needed when carbon becomes regulated may place the Commonwealth at a disadvantage in such a new regulatory environment, and certainly would forego the first-actor benefits that may accrue to states that position themselves early. The name of the game in preparing for carbon regulation is to have the ability to readily match sources and sinks. It will be absolutely crucial to pick excellent sequestration sites. Front loading the time and effort to pick those sites will position the Commonwealth favorably.

It is also critical, as pointed out by the MIT study *The Future of Coal*, to demonstrate geological sequestration of carbon dioxide (CO_2) on a significant scale:

> …CO_2 capture and sequestration (CCS) is the critical enabling technology that would reduce CO_2 emissions significantly while also allowing coal to meet the world's pressing energy needs…What is needed is to demonstrate an integrated system of capture, transportation, and storage of CO_2, at scale… At present government and private sector programs to implement on a timely basis the required large-scale integrated demonstrations to confirm the suitability of carbon sequestration are completely inadequate…Government support will be needed for these demonstration projects as well as for the supporting R&D program.[3]

Pilots are a vital step toward plant level scale-up and to accelerate the investment and development that will drive down initially high technology cost curves. No state has moved to plant level scale-up yet, but many want to. The lack of pilots and scale-up tests are a

[3] http://web.mit.edu/coal/The_Future_of_Coal.pdf

fundamental barrier to driving down the high-costs curve of currently available technology and to justify adoption of CCS technology. Markets alone won't close this research gap due to these cost barriers. Those barriers need to be addressed simultaneously with pilots and demonstration projects.

While cost is a major constraint, private and Federal investment is available. It is much easier to mobilize these funds with state leadership. To the extent that Federal funds require Congressional support, leadership requests by Governors are critical. Every regional and local geological formation has unique characteristics that affect feasibility and requires location-specific testing. Thus, many states are effectively in a race for funds and are lobbying for more to be invested in state-targeted pilots. Pennsylvania lost this race two years ago when the Battelle Labs, the project leader for the MRCSP, selected Ohio for one of the three pilot projects developed by the partnership's Phase II project (one each in Kentucky, Michigan, and Ohio) In addition, despite offers from DCNR for a potential sequestration source and sink in Pennsylvania, Battelle chose Ohio as the site for a long-term CO_2 injection and monitoring project for Phase III of the U.S. Department of Energy (DOE)-funded project. West Virginia and other states are also vying for funds now.

Governor Rendell has announced his intention to propose a comprehensive global warming strategy. Pennsylvania is already addressing a comprehensive set of technical, economic and policy issues related to clean coal and geological sequestration (as well as similar issues regarding terrestrial sequestration) through the work of DCNR. The Department of Environmental Protection (DEP) has made huge advances in alternative energy policy and deployment, and is nearing completion of a variety of complementary GHG reduction strategies that ensure a smooth transition to reduced carbon economy. Thus, the Commonwealth is well-situated to advance pilots as a part of the bridge building to new policies and markets, so that the adoption of geological sequestration can occur on a managed time frame. Such pilots would not occur in a vacuum and have a high likelihood of payoff for Pennsylvania. Few other states are able to claim this level of readiness and commitment.

The market stakes for clean coal adoption in Pennsylvania are high. Federal carbon constraints are likely by 2010. There is high regional demand for Pennsylvania's coal-based generation (35% of the electricity generated in-state is exported, according to DEP). Without clean coal technology these markets will shift to alternate supplies with the introduction of carbon constraints. First movers are likely to gain long-term advantage by installing long-term capacity with CCS technology upgrades. If Pennsylvania misses the early window, its market share could degenerate and there could be substantial electricity market disruptions.

It would be very difficult for a state policy to be simultaneously in favor of coal and climate protection without embracing geological sequestration and making a significant commitment – and investment – in its development. Pilot projects and related policy developments demonstrate this commitment.

Other states are taking heed:

- In Kansas, HB 2419, the Carbon Dioxide Reduction Act, was signed into law in March, 2007, and provides tax incentives and accelerated depreciation provisions for the sequestration of CO_2 through underground storage, and requires regulations to be established by July 2008[4].
- In Texas, H.B. 3732 (2007) will make it the first state to certify CCS for enhanced oil recovery (EOR). The bill also provides related tax breaks[5].
  - The Texas Legislature also funded a site screening process and expedited permitting for a potential FutureGen plant, and approved $22 million in grants and incentives for low-emission projects[6].
  - Texas has already agreed to own the proposed FutureGen site and assume liability for carbon storage.
- California, New Mexico, Oregon, and Washington are examining the promotion of CCS policies[7].
  - California's SB 1368 pushes utilities to rely on clean sources, including CCS[8].
- New York is funding CCS research[9].
- The Ohio Assembly appropriated $2.3 million to drill a state-owned 9000+ foot well to assess geological storage capacity[10].
- Illinois' legislature is considering bills to assume some responsibility for FutureGen.

While requiring considerable public investment (that can be highly leveraged with promised Federal funding, utility and, perhaps, foundation collaboration), a commitment to geological sequestration, including the ambitious goal of funding a pilot project, represents a huge opportunity for Pennsylvania to once again assert national leadership in advanced energy development. The political impact of such a commitment, as well as the scientific advance that it would enable, cannot be overstated. It would also open the door to economic opportunities for Pennsylvania.

Just as powerful would be an effort by the Governor to galvanize collaborative action among other "coal states" by convening their governors to work to advance the deployment of the cleanest coal technologies and CCS.

What is Geological Sequestration?

Geological sequestration is the injection and storage of CO_2 in underground rock layers, or "sinks," that are capped with impermeable rocks (confining units) to prevent leakage. The primary attraction of geological sequestration is the potential for direct and long-term storage of large volumes of captured CO_2 emissions in close proximity to the CO_2 sources. Geological

[4] http://www.governor.ks.gov/news/NewsRelease/2007/nr-07-0329a.htm
[5] http://www.legis.state.tx.us/tlodocs/80R/analysis/html/HB03732H.htm
[6] http://www.mtclimatechange.us/ewebeditpro/items/O127F10895.pdf
[7] *Ibid*
[8] http://www.ucsusa.org/assets/documents/global_warming/SB-1368-Fact-Sheet.pdf
[9] http://www.mtclimatechange.us/ewebeditpro/items/O127F10895.pdf
[10] http://www.ohiodnr.com/Home/ogcim/ogcim/Co2/tabid/17870/Default.aspx

sequestration is a proven technology in many parts of the world, and can be employed to enhance the recovery of oil and natural gas from both conventional and unconventional reservoirs.

Sinks

Geological sinks include a variety of reservoir types, each having unique physical and chemical properties that present both opportunities and challenges to be considered before storage begins. In Pennsylvania, the four main categories of geological reservoirs considered important potential sinks, as determined by the Midwest Regional Carbon Sequestration Partnership (MRCSP) Phase I study, include:

1. Deep saline formations – rock layers deeper than 2,500 feet that contain salt water in the pore spaces between sediment grains. A depth of 2,500 feet or greater is necessary to store CO_2 in a liquid form, which takes up much less space than does CO_2 gas.
2. Depleted oil (and gas) fields – areas where there is still much oil left in the ground that potentially could be removed by pumping CO_2 through the reservoir. Given the right conditions, CO_2 will enhance oil recovery while remaining locked in the rock layers.
3. Deep unmineable coal beds – layers of bituminous and anthracite coal that are too deep and/or too thin to mine under current economic conditions. Unlike saline formations, coals adsorb CO_2 onto their organic matrix. Because CO_2 does not need to be in a miscible (liquid) state, the coal beds do not have to be 2,500 feet or deeper.
4. Organic-rich (carbonaceous) shales – shale layers deep underground that contain large concentrations of organic material in their rock matrices. These rocks typically act as the sources of the hydrocarbons trapped in producing reservoirs. They also act like coal by adsorbing CO_2 onto the organic matrix in the rock

Another type of geological sink, which has not yet been studied in Pennsylvania but which could have great potential for CO_2 sequestration, is underground salt-solution cavities. Certain areas of northwestern and north-central Pennsylvania, in particular, are underlain by many square miles of thick rock salt deposits that potentially could be used for CO_2 storage if cavities were created through the action of pumping water into the salt to dissolve it. Dissolution of bedded salt for the storage of fluids such as natural gas is a well-established technology. A side effect of this action would be to create large quantities of saline water that would have to be safely disposed of in an environmentally friendly manner. It is possible that the salt could be separated from the water through evaporation. The resulting rock salt could then be processed and sold as table salt, road salt, or as a feedstock for the production of chemicals, among its many uses.

Confining Units

Confining units are geological formations or structures that, as a result of their chemical and/or physical properties, act to block the movement of fluids in the subsurface. Dense rocks, such as limestones and basalts, have interlocking crystalline structures that generally result in very low porosity and permeability. More plastic rocks, such as shales and salt, typically have high porosities but very low permeabilities. All such rocks prevent or substantially reduce fluid flow, acting as shields against the migration of CO_2, natural gas, water, etc. Faults and fractures can also act as confining units, especially if they have been sealed by mineralization, or if movement has resulted in the juxtaposition of impermeable rocks across the fault zone from a qualified sink. Confining units are absolutely essential when considering geological sequestration targets. Without them, leakage could be a major potential problem.

Pennsylvania's Geological Sequestration Capacity

The sequestration capacity in Pennsylvania, as calculated during the MRCSP Phase I project, is roughly equivalent to more than 250 years worth of emissions at present rates[11]. That capacity is unequally distributed among numerous deep saline formations, organic-rich shales, oil and gas fields, and coal beds. Each formation has its own set of geological conditions that affect sequestering potential.

The prospects for geological sequestration in Pennsylvania are best understood in western and north-central Pennsylvania where drilling for oil and natural gas production, and for natural gas storage, has demonstrated that various formations have the physical characteristics necessary for the injection and storage of fluids. Only a few small areas of central and eastern Pennsylvania have been drilled and/or are being used for gas storage. Wells generally are few and far between, but provide a beginning basis for evaluation of those areas for geological sequestration.

Prospects for Enhanced Hydrocarbon Recovery

In some cases, the injection and storage of CO_2 could reasonably be expected to enhance the recovery of crude oil from depleted fields, or methane gas from deep, unmineable coal seams and organic-rich shale formations. These would add value that could help offset the expected large cost of capturing and sequestering CO_2, particularly in today's economic climate. However, there is much research that needs to be done to determine if enhanced recovery of oil and natural gas is a viable option. Most of Pennsylvania's oil fields are shallower than 2,500 feet, and CO_2-enhanced recovery has, thus far, not been attempted within the state. Also, enhanced recovery of methane from coal and shale are still very much theoretical with little (so far) practical application.

[11] Based on preliminary estimates derived from calculations as described in the Midwest Regional Carbon Sequestration Partnership Phase I Report, http://198.87.0.58/PhaseIReport.aspx. Note: the 250-year figure is based on only 10% of the total potential capacity of just the formations studied during Phase I, i.e, the major rock formations in the subsurface of western and north-central Pennsylvania. It is likely that it will be significantly reduced as better data are used in subsequent studies. However, the total capacity of all sinks throughout Pennsylvania, including in the central and eastern parts of the state, will probably add up to more than 100 years worth of present day emissions once a complete inventory has been done.

Current Status of Geological Sequestration

There is significant domestic and global experience with post-combustion carbon capture technology. Commercial post-combustion systems exist to capture CO_2 from exhaust gases using chemical "stripping" compounds such as amine. However, stripping is applied today to very small portions of flue gases (tens of thousands of tons from plants that emit several million tons of CO_2 annually) from a few coal-fired power plants in U.S. that sell captured CO_2 to the food/beverage industry. Post-combustion technologies have much higher costs and energy penalties than alternative, pre-combustion capture[12].

There is also a growing body of experience with pre-combustion carbon capture technologies. Integrated Gasification Combined Cycle (IGCC) power-only plants are not widely deployed – only two IGCC power-only plants operate in U.S. – and the technology is only about 20 years old. However, the early availability issues associated with the technology appear to be resolved today[13]. There are commercially demonstrated systems available for pre-combustion CO_2 capture from IGCC – the same techniques used in industrial plants to separate CO_2 from natural gas and to make chemicals, e.g. ammonia, out of gasified coal. These technologies are also used for EOR. The pre-combustion capture approach is ready today for use with IGCC power plants[14]. The principal obstacle for broad application of pre-combustion capture to new power plants is economic, not technical. Indeed, coal plants in design today can employ proven IGCC and pre-combustion capture systems to reduce CO_2 emissions by about 90%. The problem is that the technology carries with it an energy penalty that has been estimated as high as 40%. (See Appendix 1.) Estimates of the costs of deploying CCS with coal-fired power plants and attendant energy penalties are changing continually, and will remain approximations until commercial-scale CCS plants are built and in operation.

There is also a significant domestic and global experience base for injecting large amounts of CO_2 into geological formations. EOR technology is several decades old. High pressure CO_2 is being injected every day into oil fields around the world, delivered by pipelines spanning as much as several hundred miles. For example, the SACROC (Scurry Area Canyon Reef Operators Committee) unit in Texas, the first large-scale CO_2 EOR project in the world, has been operating for over 35 years and has sequestered 68 million tons of CO_2 to date. Currently, the unit is injecting 5 million tons per year and producing 30,000 barrels of oil[15]. And the Weyburn-Midale oil field in Saskatchewan, Canada, is currently the world's largest full-scale, in-the-field study of CO_2 storage in conjunction with EOR. The project is expected to sequester approximately 30 million tonnes of CO_2 and produce about 155 million barrels of oil during its lifetime[16]. Today in the US, more than 35 million tons of CO_2 are injected annually in more than 70 projects (80% of that CO_2 is derived from natural formations rather than captured from industrial sources).

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[12] Natural Resources Defense Council
[13] *Ibid*
[14] *Ibid*
[15] Hagist, Pete, Vice President Ops, Whiting Oil & Gas Co., *Coupling enhanced oil recovery with the demand for CCS – A viable interim solution for power generating facilities.* Speech given at the Sixth Annual Conference on Carbon Capture & Sequestration, Pittsburgh, May 9, 2007.
[16] http://www.ptrc.ca/weyburn_overview.php

The longest running geological sequestration project not used for EOR, the Sleipner project in the North Sea[17], began in 1996. Natural gas in the Sleipner West gas field contains large quantities of CO_2. In order to avoid paying taxes on any CO_2 emitted to the atmosphere, the Norwegian oil and gas company, Statoil, which owns the field, has been stripping CO_2 from natural gas and re-injecting it back into a saline aquifer beneath the sea. A partnership that includes other energy companies as well as Statoil, several countries bordering the North Sea, and the European Union is monitoring the CO_2 to verify that it remains trapped in the aquifer.

While there is, indeed, significant global experience with carbon capture and geological sequestration, it has yet to be combined and applied on a scale compatible with the emissions of a coal-fired power plant (on the order of about 5 million tons CO_2/year). There are no major carbon capture and storage (CCS) projects currently underway to demonstrate the integration of technologies with coal-fired power plants. This integration of available technologies, to best suit the Pennsylvania context, needs to be demonstrated.

Requirements for Siting Geological Sequestration Projects in Pennsylvania

Assessments and Pilots

DCNR has developed a two-step approach to further characterize and demonstrate the Commonwealth's geological sequestration resources. The first step is to assess, map, and test Pennsylvania's geological sequestration resources in central and eastern Pennsylvania. DCNR believes that state investment is both needed and strategic – with Federal funding approved for geological sequestration research in the 2007 Federal energy bill, the Commonwealth would be in a strong position to leverage federal dollars with an aggressive geological assessment plan in place.

The second step is to facilitate and/or fund an at-scale pilot geological sequestration project.

These steps are described more fully below.

Step 1: Basic Geological Assessment for Central and Eastern Pennsylvania

Prospects for sequestering CO_2 in the subsurface of central and eastern Pennsylvania might be good, but there are few data on the underground extent and physical/chemical characteristics of the geological formations in those areas to support an immediate consideration of those rocks as targets for CO_2 sequestration. To date, only 170 wells have been drilled in the eastern two-thirds of the state, as compared with an estimated 350,000 drilled in western and north-central

17 http://www.statoil.com/STATOILCOM/SVG00990.nsf/Attachments/co2MagasinAugust2007/$FILE/CO2_eng.pdf

Pennsylvania since 1859. Forty-four percent (74) of those 170 wells exist in one county (Bedford). It would take approximately 150 years and many trillions of dollars of drilling in the central and eastern part of the state to match the number of wells and the quality of subsurface data that already exist in western and north-central Pennsylvania.

The first step to evaluate the potential for geological sequestration in the central and eastern parts of Pennsylvania is to map out suspected reservoirs as a precursor to performing basic technical analyses, such as seismic surveys, drilling wells, and performing in-depth reservoir analyses in site-specific areas. This would necessitate examining existing geologic maps and performing exhaustive literature/file searches for all data pertaining to geology/engineering characteristics of surface rocks and known geological structures to determine if further consideration for sequestration is warranted. Data gathering and manipulation can be done remotely for those areas where the geology and engineering characteristics of the rocks are well known, i.e. where cores have been taken for highway, bridge, dam, and building construction, for quarrying or mining operations, or where the Pennsylvania Geological Survey has obtained shallow cores during the course of routinely mapping an area. A search of historical records and the application of modern geological concepts will be necessary where field mapping has not been done within the past 50 years.

In these areas of the Commonwealth that are well outside of the oil and gas fields, it will be necessary to do as much literature search of potential sink formations as possible, and then extrapolate the data into the subsurface using modern concepts. The use of remote sensing data, such as aeromagnetic and gravity data, and imagery (side-looking radar imagery, LiDAR, etc.), could provide assistance to the evaluation. It might be necessary to drill and core numerous holes to test the changes in physical characteristics of rock layers between outcrop and a depth of a few hundred to 1,000 feet or more.

The cost for Step 1 would depend on who does the literature/file evaluation:

- If performed by DCNR (geologists with the Bureau of Topographic and Geologic Survey), the cost would be substantial, but wouldn't require as much funding if done by an outside entity. The MRCSP Phase I study, which was, for all intents and purposes, restricted to western and north-central Pennsylvania, required two years of file review, geophysical log interpretation, geological mapping (both by hand and by computer), and report writing by three staff geologists, a GIS specialist, and several interns. The initial projected cost of $129,000 (most of it from DOE subcontract) was for a one-year study and was based on the staff spending only 10 to 15 percent of their time on the project. The actual final cost to the Bureau was much higher, between $260,000 and $300,000, because they actually spent 65 to 75 percent of their time over a two-year period, and probably would have spent 100 percent except for other routine duties that required their attention.

  A similar effort in central and eastern Pennsylvania could easily involve at least five years of work by six or more geologists, several GIS specialists, and many interns to compile the information necessary to even begin an evaluation of the type carried out in MRCSP Phase I. All of the data analyzed for MRCSP Phase I were located in-house, and much of it was in digital format, which made searching and manipulating it relatively easy. Probably only a minor amount of data pertaining to rocks in the subsurface of central and eastern Pennsylvania resides in the files of the Bureau of Topographic and Geologic Survey's Middletown and Pittsburgh offices. Requests would have to be made to the Pennsylvania Department of Transportation, Pennsylvania Turnpike Commission, and a large number of mining and engineering companies for access to drill cores and core data. These cores and data would then need to be studied in combination with surface mapping data to extrapolate the necessary physical characteristics of the rocks at a sufficient depth for sequestration to occur.

The total cost of the project would depend on how many people were involved and how much of their work time could be devoted to the study, but it would probably exceed $600,000.

- If this work were to be performed by a contractor it would have to be bid out. A typical small oil and gas contractor will charge $100 to 150 per hour for evaluating a potential lease. A larger company could easily charge 10 times that amount. More than likely, a bid would be somewhat, but not significantly, lower. Assuming the work takes five years, and the contractor spends 75 percent of his time on this project, the work would require between $800,000 and $11,800,000, depending on the consultant.

As a result, it makes both logical and fiscal sense to let the Bureau of Topographic and Geologic Survey handle at least the majority of the workload.

The results of this preliminary assessment could be mapped to provide a statewide inventory of candidate sequestration sites. This information could also be made available to industry. It would provide the basic information necessary to identify target sinks that could be explored on an individual site basis, described more fully below under Geological and Engineering Assessment.

Step 2: A Pilot Geological Sequestration Project

A pilot project could be performed in western or north-central Pennsylvania simultaneously with, or secondary to, mapping and assessing the geological sinks in central and eastern Pennsylvania. Aside from removing CO_2 from the atmosphere and storing it underground, the principal focus of a geological sequestration pilot project is on demonstrating that COa_2 injection, storage, measurement, and monitoring are safe and effective in the state. This will require significant state resources, both financial and staff time in several agencies and commissions. Such a project, whether it involves funding and/or actual construction, requires that numerous issues, as discussed below, will have to be considered before the proper site can be chosen for injection and monitoring.

Leveraging the State's Investment

There is significant opportunity to leverage the state's investment with Federal and private resources. Several Pennsylvania utilities have indicated a serious interest in geological sequestration. Indeed, it will be necessary for the Commonwealth to partner with the oil and gas industry, fluid transportation (pipeline) industry, and the carbon-source industry (power plants, ethanol plants, etc.) whose expertise far exceeds that of any individual agency within state government.

Considerations for Siting: Location

A geological sequestration site should be chosen to provide the maximum sequestration potential and/or the maximum enhanced hydrocarbon recovery (with subsequent sequestration). In many places, but especially in western Pennsylvania, sequestration can be accomplished on the site of the CO_2 source facility due to multiple geological targets. In other cases, the CO_2 will have to be transported to a suitable site via pipeline, truck, or railroad, which will also require monitoring for safety. The ideal situation for a CO_2 producer is to contract with an oil and gas company to supply CO_2 for enhanced recovery in the oil and gas or coalbed methane (CBM) fields. Either the oil and gas company or a specialty pipeline company then would be responsible for constructing, maintaining, and monitoring the pipeline. The producer's only responsibility should be maintaining a sufficient supply of CO_2 to meet demand.

The specific location of a potential state-involved geological sequestration project will depend on:

- The location of the source of the CO_2 – a power plant or ethanol plant, for example.
- Whether private or public lands are chosen for the project wells.
- The subsurface rock formation(s) considered most attractive for sequestration purposes.
- The quality of the geological and engineering data at hand for a preliminary evaluation of the target formation(s).

CO_2 sources occur in many areas of the state (see Figure 1 below), particularly in the larger urban areas of eastern and western Pennsylvania. Except for north-central and south-central Pennsylvania, there is almost no limitation on the siting of a project from the perspective of source location.

Considerations for Siting: Technology

The technology necessary for carbon capture will depend on the available source. The technology for stripping CO_2 from flue gases in coal-fired power plants is under development, but is not yet economically feasible (see Annex 1). In addition to aggressively pursuing any available federal funding, consideration should be given, in consultation with DEP and the Pennsylvania Department of Community and Economic Development (DCED), to publicly subsidizing full spectrum CCS pilots, i.e. pilots that test capture technology as well as storage capacity and safety. Carbon capture R&D can directly lead to the development of manufacturing capacity and employment opportunities for the state.

MRCSP has provided some rough estimates of the cost of a full-spectrum, at-scale CCS pilot project in developing an application for Phase III funding:

- A preliminary project budget of $40 million for a four-year injection test at $10 million per year.
- $15-$20 million for infrastructure (injection/monitoring wells, CO_2 compression/cleanup equipment, and some above-ground piping).
- Additional funding for six years of monitoring after the four-year injection period has ended (details on how much this will cost MRCSP are still confidential while awaiting approval and funding from DOE).

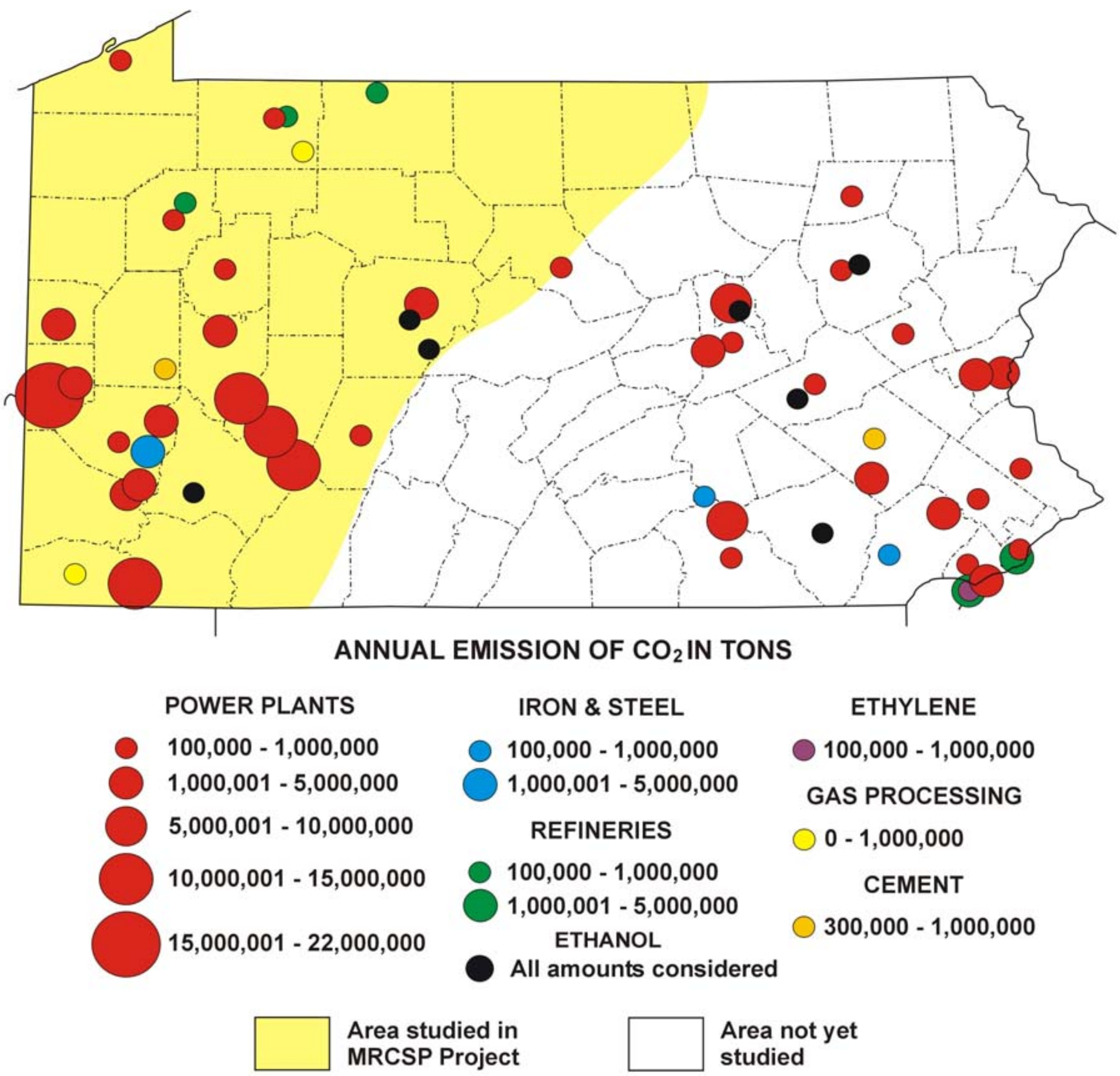

Figure 1: Map of Pennsylvania showing locations of large sources of CO_2

If, however, the required level of leveraged public investment in such an effort is prohibitive, pilots could proceed focusing solely on proving geological sequestration capacity and safety. This approach would be simpler – and cheaper – and would require that pilots obtain the CO_2 from an industry that produces an almost pure stream of the gas, such as an ethanol or gas processing plant, rather than from a coal-fired power plant. Ethanol plants ferment liquid fuels from plant material, whereas gas processing plants remove impurities such as CO_2 and water vapor, and add heating value, to low BTU gases such as CBM. Both of these processes produce prodigious quantities of CO_2. Many of these relatively pure sources are situated in suitable locations from other standpoints as well (see Appendix 2 for a list of candidate suppliers, chosen because of their geographic location in western PA - areas that are well-characterized geologically).

The cost of obtaining a supply of CO_2 would depend on the supplier. It is hoped that the candidate supplier would be a partner in the pilot project and willing to provide a sufficient supply of CO_2 for the project to be an effective demonstration of geological sequestration in Pennsylvania. The cost for using a pure stream of CO_2 from, for example, an ethanol plant, typically involves the cost of compressing and drying the gas to a transportable liquid, which is significantly less than the capture and compression costs at a power plant where the CO_2 first has to be stripped from flue gases. The cost of acquiring CO_2 from an ethanol or gas processing facility has been estimated at between $15 and $30 per ton (which includes compression and transportation a short distance).

A third alternative would be to purchase numerous truckloads or tanker cars of liquid CO_2 from a commercial source of the gas, such as a food-grade or industrial supplier for use in a pilot injection well. The cost of food-grade liquid CO_2 is about $100 to $200 per ton depending on supplier, transportation costs, etc. However, since the market for gases for the food and chemical industries is so volatile, the cost could range from a few dollars per ton to many tens of dollars per ton by the time a pilot test well has been drilled. Tank trucks typically hold about 20 tons and railroad tank cars typically hold about 50 tons of liquid $CO_{2,}$ so the cost for one truckload would be between $2,000 and $4,000 whereas one tank car load would cost between $5,000 and $10,000. The advantage of going this route is that commercial grades of liquid CO_2 are readily available in large quantities from many industry sources. The major drawback is that it would almost guarantee a very small amount of the liquid would be used in the test hole. To pump approximately 350,000 tons of CO_2 into a test reservoir would require 17,500 tank trucks or 7,000 railroad tank cars, ranging in cost from $35 to $70 million. The cost of a one million ton pilot would be $100 to $200 million dollars!

Since any meaningful pilot project would require several hundred thousand to several million tons of CO_2, the most efficient and cost effective source of CO_2 at that scale would be a gas processing plant or ethanol plant. Both processes produce a large, relatively pure stream of CO_2. Partnering with such a facility would substantially reduce costs of both supply and transportation, but ultimately the cost of sequestering several hundred thousand to several million tons of CO_2 would still be millions of dollars.

Pennsylvania Pilot – Western Pennsylvania First

The geology, including the physical and chemical characteristics, of the rocks in the subsurface of western and north-central Pennsylvania are fairly well documented through the enormous amount of oil and gas well drilling that has taken place over the last 150 years (estimated at 350,000 wells since the Drake Well in 1859). Figure 2 below shows the locations of approximately 180,000 wells, the number for which DCNR and DEP have some record. Figure 3 below shows the result of all that drilling over the years, the historical locations of produced oil and natural gas. Therefore, siting criteria probably will be less resource intensive in those areas than in other parts of the Commonwealth. The only way to obtain similar geological data in central and eastern Pennsylvania is to drill an equally enormous number of wells to various depths in that area. Such a feat would take many trillions of dollars and many, many years, and so for all practical purposes is not a realistic option.

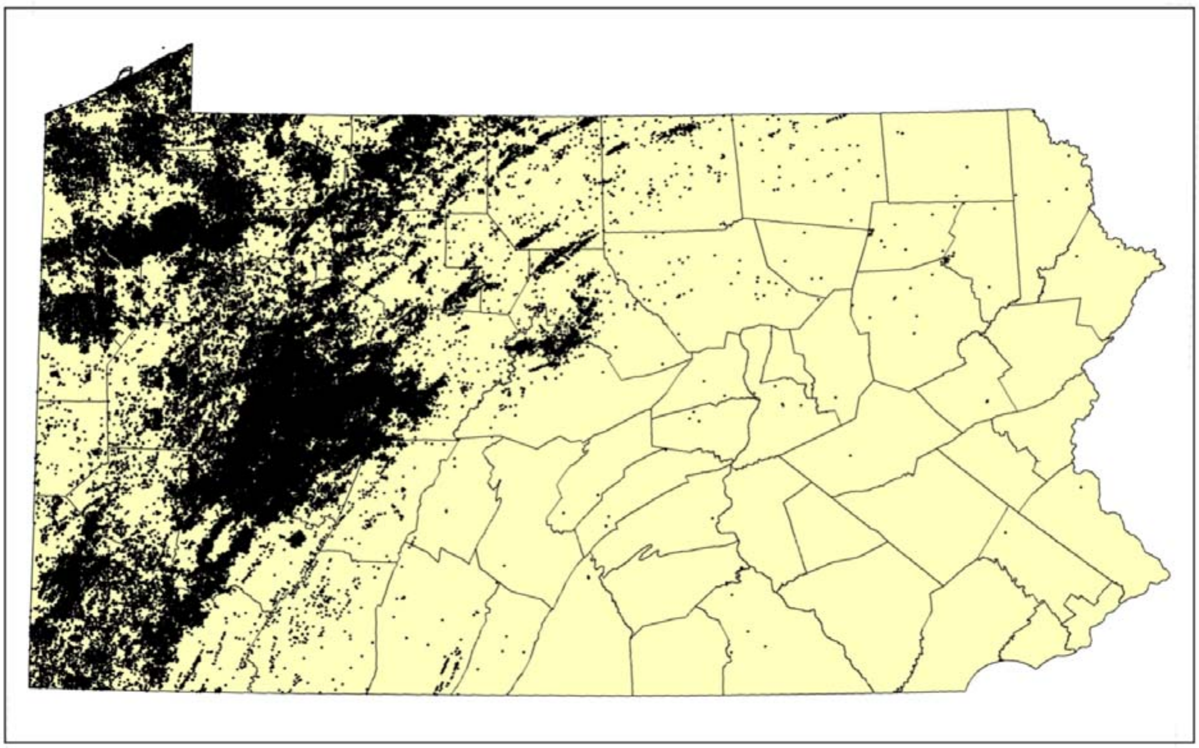

Figure 2: Map of Pennsylvania showing the locations of oil and gas wells for which the state has records (approximately 180,000).

The geology of central and eastern Pennsylvania is much more complex than that of western and north-central Pennsylvania where the rock layers are essentially flat lying. East of the Allegheny Mountains the rock layers are tightly folded and faulted; their outcrop lines shown on a map form a crazy-quilt pattern of curves, broken lines, and zigzags (see Figure 4 below). Formations lying thousands of feet underground at one spot often are exposed at the surface just a mile or two away. In southeastern Pennsylvania, where the rocks have undergone tremendous heat and pressure from mountain building, most of the rocks have been altered to gneiss, schist, slate, or marble having few if any of the characteristics suitable for sequestration. The one potential

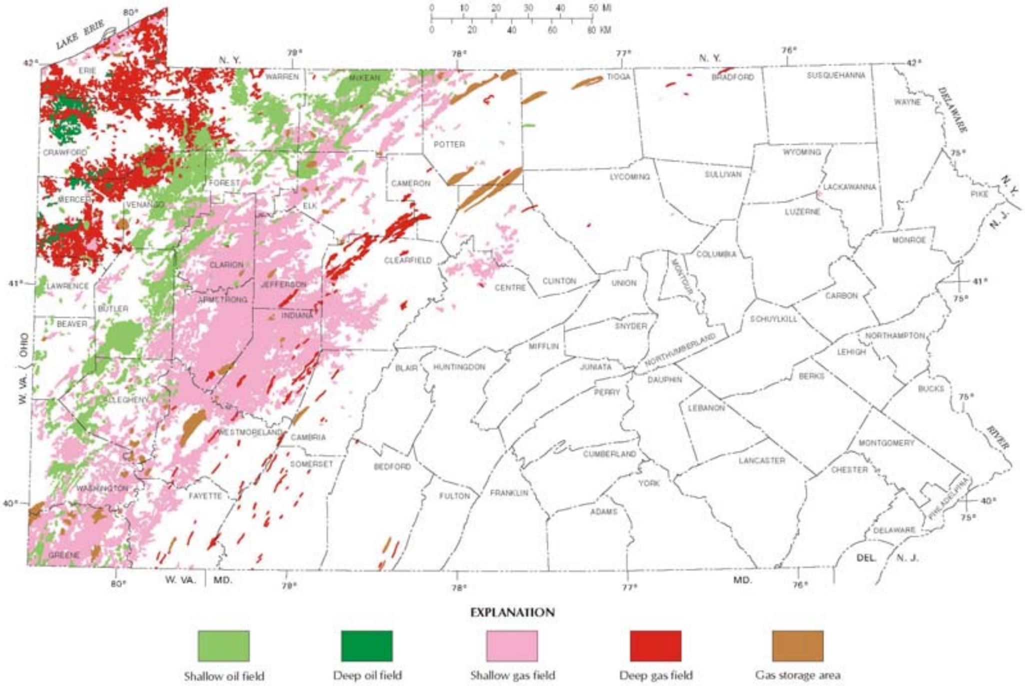

Figure 3: Oil and gas field map of Pennsylvania

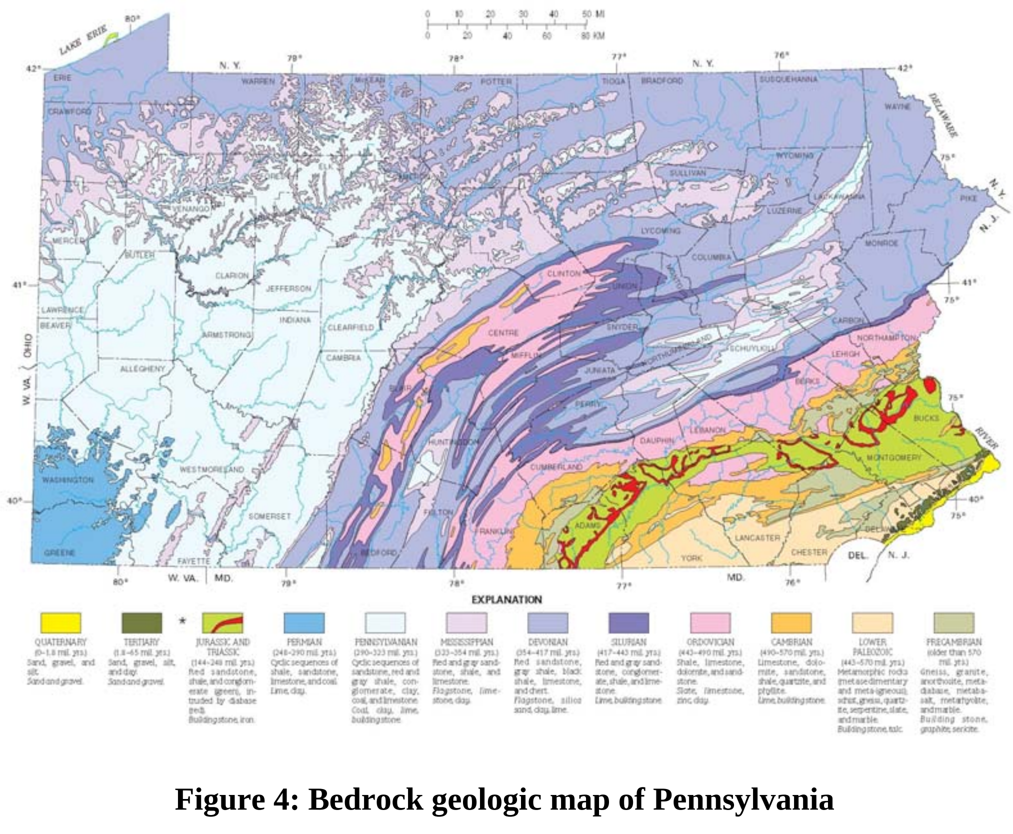

Figure 4: Bedrock geologic map of Pennsylvania

bright spot in this area of Pennsylvania is the combined Newark and Gettysburg basin, shown in Figure 4 as the bright green and red swath running from the Maryland border in Adams County to the New Jersey border in Bucks County. These rocks consist of a sequence of conglomerates, sandstones, and shales in places as much as 11,000 feet thick that were deposited in lakes during the early days of the dinosaurs when the Atlantic Ocean was forming between what are now North America and Africa. Less than six wells are known to have been drilled in this basin to date, but the surface rocks are fairly well documented, and the most recent wells drilled (one each in Bucks and Montgomery Counties, both in 1985) could provide evidence that the rock layers will be significant sinks and confining units in that part of the state. Data are sparse because the operator was uncooperative with the oil and gas regulatory office (DEP), but there might be enough in-house data derived from other sources to do a preliminary evaluation on the rocks. A company from Michigan is currently testing these rocks in Bucks County for their oil and gas potential, and has promised to be more cooperative in supplying subsurface data to DEP and DCNR as they proceed to drill and complete wells. It might take several years to develop a valid picture of the subsurface potential of the basin for geologic sequestration, but the rocks of the basin may prove to be the most significant, if not the only, sinks available for massive sequestration in southeastern Pennsylvania.

Each geological formation, regardless of where it occurs, has its own unique characteristics, particularly as related to storing fluids. Leakage along faults and fractures, and even fluid flow from depth to the surface at the nearby outcrop, would need to be critically evaluated. However, all of Pennsylvania has been mapped at the surface, so there is at least a general understanding of stratigraphic relationships, structural attitudes (folds and dips), discontinuities (faults and fractures), and physical characteristics of the rock units. Siting of a potential geological sequestration project in central and eastern Pennsylvania will require far more thorough evaluation than in western Pennsylvania because of the lack of subsurface data, but it could be done given the proper resources.

A site should be chosen where there are good technical data for evaluation of the underground rock layers. An area where many oil and gas wells occur, for example, would provide a wealth of information from geophysical logs run in the wells as a matter of standard practice. Some of the wells might have washed drill cuttings on file, or the companies might have taken some core samples for evaluation by a testing laboratory. All of these would provide excellent data sources for evaluation of the formations penetrated during drilling.

Mineral Rights = Storage Rights

Perhaps the most problematic element of CO_2 sequestration is the issue of ownership of the rock layers proposed to act as the sink. The complications of land and mineral-right ownership and title in Pennsylvania are complex enough that excellent prospect areas for sequestration projects might be entirely unsuitable due to unresolved ownership issues. Obtaining ownership and CO_2 sequestration rights on private lands could be a serious obstacle to the long term objective of sequestration in Pennsylvania.

Given the foregoing, state-owned land should be the first choice when considering a state-sponsored pilot sequestration project. Where possible, the Commonwealth, whether DCNR or (to a lesser extent) the Pennsylvania Game Commission, traditionally negotiates for all legal rights, including mineral exploitation and fluid storage rights, when purchasing acreage for forest stands or game lands. However, if the sequestration wells are to be located on state-owned land that have few or no problems related to surface and mineral-right ownership, the geographic limitations become more evident. State forest land, in particular, occurs largely in central Pennsylvania (see Figure 5 below), well away from the major CO_2 sources. State game lands are more widely scattered across the state, but typically they have smaller areas that might be less suitable for a large sequestration project involving one or more injection wells and several monitoring wells.

The Commonwealth could consider the possible use of eminent domain to obtain the necessary rights on private land, or on state land from which the mineral rights were stripped, but this is typically considered a draconian measure and should be used only as a last resort.

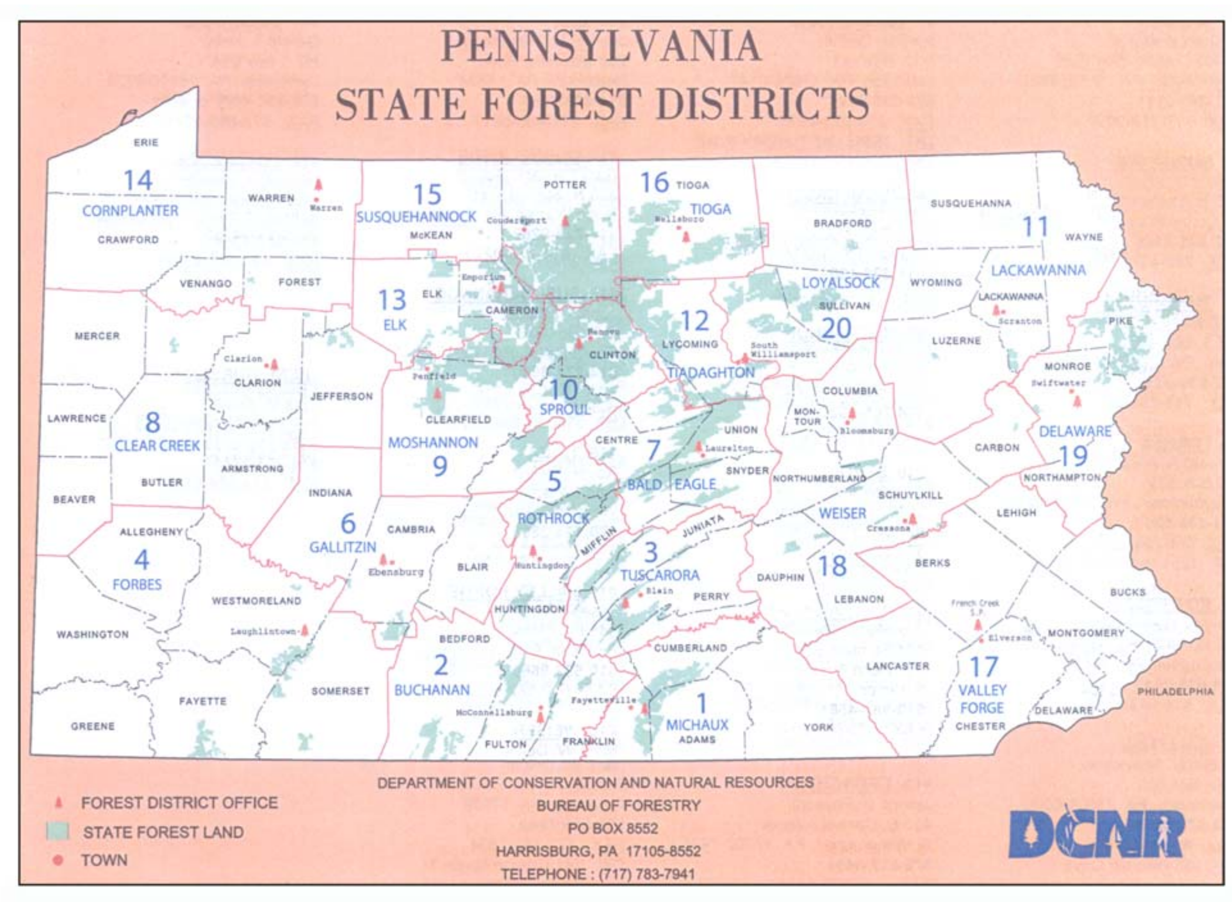

Figure 5: Map of Pennsylvania showing locations of state forest land.

Geological and Engineering Assessment

Each site chosen for sequestration potential will have to be thoroughly evaluated based on geological data collection and analysis. Such data, combined with the data from various regional and local fluid injection programs (including waste disposal wells and standard-practice hydraulic fracturing of hydrocarbon reservoirs in oil and gas wells), can significantly enhance the confidence level in both the capacity and the security of any particular geological sink. In areas such as central and eastern Pennsylvania where there are few or no well data, and where there have been no attempts to dispose of fluids underground, the degree and the cost of evaluation will necessarily be higher than in the oil and gas field areas of the Commonwealth.

Several tasks will be required to evaluate the storage potential of a particular rock formation at a particular site. Pilot Step 1 is identical to the task proposed above for evaluating central and eastern Pennsylvania; it is included in the event that a preliminary state-wide assessment is not undertaken.

- **Pilot Step 1 - Perform exhaustive literature/file searches** for all data pertaining to the geology/engineering characteristics of the subsurface rocks, and an evaluation of any existing data at or near the potential site. As explained above, for sites in central and eastern PA, we should utilize existing data on surface rocks and known geological structures to determine if further consideration for sequestration is warranted. Data gathering and manipulation can be done remotely for areas where the geology and engineering characteristics of the rocks are well known, such as in established oil and gas fields. However, it should be pointed out that many such fields are very old and do not have sufficient data for critical evaluation. In such cases, a search of historical records and the application of modern geological and engineering concepts will be necessary.

  For sites in areas of western and north-central Pennsylvania outside of the oil and gas fields, it will be necessary to do as much literature searching of potential sink formations as possible, and then extrapolate the data into the subsurface using modern concepts. The use of remote sensing data, such as aeromagnetic and gravity data, and satellite imagery such as side-looking radar and LiDAR, could assist with the evaluation. It might be necessary at some point to drill and core a shallow hole to test the changes in physical characteristics of rock layers between outcrop and a depth of a few hundred to 1,000 feet.

  The cost for Step 1 would depend on who does the literature/file evaluation:

  - A literature/file evaluation of a potential site by DCNR (Bureau of Topographic and Geologic Survey) geologists would probably require several hours to several days, depending on the availability and quality of data. The current salary and benefits for a Senior Geologic Scientist with 5 years of state employment is about $32 per hour. Therefore, the cost to the Commonwealth probably would be between $160 and $1,000.

- As explained above, a typical small oil and gas consulting geologist will charge between $100 and $150 per hour, whereas a larger firm might charge between $1,000 and $1,500 per hour. A literature/file evaluation of a potential site would therefore cost between $500 and $45,000.

These numbers are, of course, just estimates based on reasonable approximations of how long it would take to do a critical evaluation of a potential site.

- **Pilot Step 2 - Acquire, process, and analyze seismic reflection data**. This will be critical in determining any geological structures (folds, faults, etc.) that exist below a prospective project site. This step is especially important in areas outside known oil and gas fields where the geology is not well understood or can only be extrapolated from distant areas.

  Numerous seismic surveys have already been run in many areas of Pennsylvania as part of regional oil and gas exploration programs (the locations and extent of seismic survey data are currently unknown, but could be researched through oil and gas industry contacts). It might be more advantageous and less expensive to purchase existing data than to run and process new seismic surveys.

  In order to best determine any geological structures in the area, there should be at least two seismic surveys run approximately perpendicular to each other near the proposed project site. The length of the survey lines will depend on the proposed depth of a sequestration well, but a rule of thumb is that each line should be at least five to 10 miles long (depending on the depth of the prospective sink), increasing in length as the proposed depth of the well is increased. A 3D seismic grid is recommended in areas of very complex structure.

  The cost of running new seismic surveys for a proposed well would be:

  - For 2D reflection seismic lines, a minimum of $85,000.
    - This is based on $8,500 per mile for two five-mile long lines using VibroSeis™, the minimum amount necessary to begin evaluating structure at a depth of 2,500 feet.
    - The cost increases to about $15,000 per mile if dynamite is used, for a minimum cost of $150,000 for two file-mile long lines.
    - Two 10-mile long lines for formations at 5,000 feet would cost about $170,000 for VibroSeis™, $300,000 for dynamite.
  - For 3D seismic, which would be necessary for delineating complex structures, the cost would vary depending on grid density (how many lines are run), terrain, helicopter support, etc. Minimum cost would probably be in the neighborhood of $50,000 to $75,000 per square mile. A minimal cost of $1,250,000 for 3D seismic in a 25 square mile grid (5 miles on a side) should not be unexpected.

- **Pilot Step 3 - Drill a well**. Upon analysis of the seismic data, and assuming the seismic data do not indicate any potential problems with the target formations, the next step is to drill a well to, at least, below the depth of the lowest target sink. All DEP regulations for drilling and completing an oil or gas well must be followed, including obtaining a permit to drill and bonding the well, setting and cementing casing to protect coal seams and potable water zones, and properly disposing of drilling fluids. During drilling, any prospective injection intervals should be sampled for both interstitial fluids and fluid pressures.

The cost of drilling a well in Pennsylvania depends on many factors, especially depth. The estimated cost to drill and case a well 5000 feet deep is about \$150,000; about \$250,000 to \$300,000 for a depth of 8000 feet. Drilling costs generally increase almost exponentially (below 10,000 feet, the cost is most likely prohibitive). Because of the current flurry of interest in drilling for oil and natural gas, that price probably will rise significantly over time as companies continue competing for drilling rigs and crews.

- **Pilot Step 4 - Run an extensive suite of modern geophysical logging tools** in the hole to determine the physical and chemical characteristics of the rocks and to decide what intervals to core for laboratory analysis. These tools would include, but not be restricted to, gamma ray, neutron, density, dual induction resistivity, photoelectric, sonic, dipmeter, and others. If possible, a good borehole imaging log, such as a formation microimager (FMI), would be useful in identifying fractures, bedding, permeable strata, relative transmissivities, and other features. The logs will also be critical in deciding what intervals to core, particularly in areas where the depths and configurations of the potential targets are not well known. The geophysical logs will indicate the best intervals within the well for further evaluation as sinks and confining units.

  The cost of logging a well will vary with the suite of logs run and the depth of the hole but, in general, it could be done for about \$50,000.

- **Pilot Step 5 - Sidewall coring** of rocks identified as potential sinks and seals during log evaluation. Sidewall cores are small cylinders of rock cut from the well bore. They should be taken of all prospective injection intervals and sealing units for subsequent laboratory testing to determine porosity, permeability (vertical and horizontal), injectivity, capillary pressure, and mineralogy of each unit.

  The cost of taking and evaluating sidewall cores is about \$50,000, but will vary depending on how many samples are taken.

Only after these steps have been taken (at a cost of at least \$1.7 million) will there be sufficient data to determine if one or more geological formations have the capability of accepting and storing CO_2 in large quantities.

The total, minimum, up-front cost to the Commonwealth, should it consider funding a pilot sequestration-only project (as distinguished from a pilot capture and storage pilot), will be about \$10 to 15 million. Because of these costs, it is imperative that the state seek federal funding, which has been available to many organizations attempting pilot sequestration projects.

It should be noted that this is the minimum cost to the Commonwealth associated with a single sequestration well. It does not include:

- Additional wells for monitoring (the cost for each will depend on depth, but would be approximately in line with the cost of the injection well)
- Necessary regulatory permits
- Carbon capture, if that is the course of action chosen
- Drying and compression of CO_2 to a liquid phase
- Transportation and/or storage on site prior to injection
- Injection
- Long-term monitoring
- Financial liability in the event of leakage or other problems

The MRCSP has estimated that the costs associated with a full-spectrum CCS project, if borne entirely by the public sector and without industry involvement, would be approximately $10 million/year for five years. This includes:

- Capital costs - a compression plant is estimated to cost about $2 million per 100 ton per day of capacity; thus, ~$20 million for a plant capable of compressing 1000 tons per day.
- Operating costs - compression itself is also expensive, estimated at about $15 per ton of CO_2 compressed (assuming starting at ambient conditions and ending up at 1500 psi, electric drive at $0.10/kWh, and not including amortization of capital).

Risks Associated with CO_2 in Geological Reservoirs

Many types of risks associated with sequestering CO_2 in geological reservoirs can occur, but the primary ones are shown in Figure 6 below. These include:

- CO_2 and methane (CH_4) leakage out of the reservoir through faults and fractures, or through unplugged or improperly plugged wells
- Seismic events (earthquakes) associated with fault slippage or stressed caprock
- ground movement, particularly surface uplift resulting from overpressuring the reservoir
- contamination of groundwater supplies
- displacement of brine into non-saline aquifers.

Leakage of CO_2 that has been injected into a reservoir and/or CH_4 that is native to the reservoir can occur from a variety of factors. Although not all faults and major fracture systems pose a risk to CO2 leakage, open (non-mineralized) faults and fracture systems passing through reservoir seals can act as migration pathways for reservoir fluids, including any native or injected gases and liquids. Large faults and fault systems can be interpreted from seismic reflection data, especially from 3-D seismic, which will allow the interpreter to determine their extents and orientations. Fracture systems can be detected through the use of proper logging tools, such as the formation microscanner (FMS log), during geophysical logging of the drilled hole. However, even with use of these tools there can still be an unforeseen leakage risk; contingency planning will be a must.

The integrity of the injection and monitoring wells, and any other wells in the vicinity, are vital to a safe, reliable sequestration system. The injection well must be properly constructed and inspected during all phases of drilling, casing, cementing, and perforation of the casing and cement prior to injection. It is also imperative that any active or abandoned oil and gas wells in the vicinity of the injection well either be plugged or established to have no connection with the injection reservoir. Injecting CO_2 into an area occupied by unplugged or improperly plugged wells invites leakage, especially if the injection reservoir formerly acted as an oil and/or natural

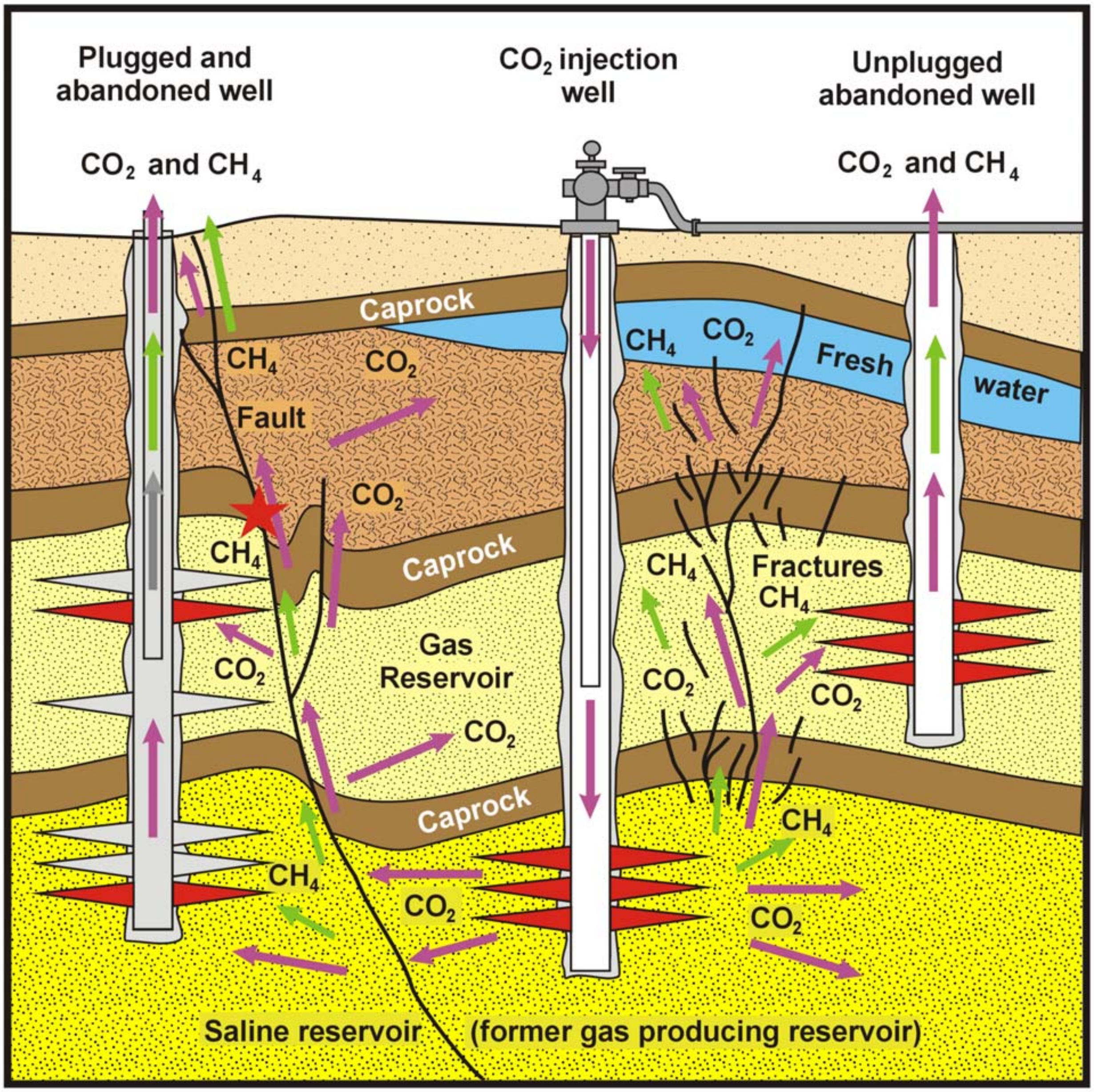

Figure 6: Potential risks associated with geological sequestration of CO_2. See the text for more detailed explanations.

gas producing or gas storage reservoir. In Pennsylvania's older oil and gas fields, many drill holes exist that can constitute a leakage pathway for reservoir gases, including injected CO_2. The safest course of action would be to avoid the oldest oil fields, such as those in the northwestern counties (especially Venango, Warren, and McKean), because those areas contain large numbers of old oil wells for which no records remain.

Although not of great concern in an area as seismically stable as Pennsylvania, storing large amounts of fluids in a rock formation could conceivably alter the rock's mechanical state and change the existing stress fields to the extent that earthquakes might occur (indicated by the red star in Figure 6). In unstable areas, a highly faulted or fractured reservoir subjected to even a small pressure increase can create instability in the rock. Earthquakes created in this manner might be small, but can still damage buildings, pipelines, and other infrastructure at the surface. An assessment of the seismic risk at the proposed injection site must occur prior to injection in order to avoid any potential damages.

Injecting CO_2 into a reservoir at a pressure different than the native rock pressure might result in sinking or uplift at the surface that will damage buildings and other infrastructure. Several situations have occurred in Pennsylvania in the past where a gas storage reservoir was overpressured, resulting in damage to structures at the surface and/or to the other wells in the area. One such case even resulted in death when a nursing home exploded due to methane leaking from the storage reservoir. Such cases are rare, but they illustrate some of the risks associated with storing gases under high pressure in a rock reservoir.

Leakage of injected CO_2 and/or native CH_4 through faults, fractures, or wells can affect groundwater supplies. Even small amounts of CO_2 in groundwater can cause significant deterioration in water quality by decreasing pH, which in turn will dissolve calcium, increase water hardness, and potentially change trace element concentrations to levels that exceed drinking water standards. Small amounts of CH_4 in groundwater have been known to find their way into houses through water wells. There are numerous cases of injury, and even death, in western Pennsylvania that resulted from natural gas entering residences through groundwater supplies, building up to flammable concentrations, and then exploding once it came into contact with an open flame.

Injection of CO_2 into a saline aquifer could create displacement of native brine into other rock formations. Such an occurrence probably wouldn't affect drinking water aquifers, which typically are very shallow, whereas any saline aquifers into which CO_2 was injected for sequestration purposes would have to be at least 2,500 feet deep. On the other hand, CO_2 injected into shallow oil reservoirs for enhanced recovery purposes or into shallow coal seams, without concern about sequestration, could affect potable water aquifers at shallower depths. Such cases are probably only of local concern but should be taken into consideration in planning the injection program.

Other Issues

Even given a geologically suitable site with clear mineral rights ownership, there are still other issues that need to be resolved before a sequestration project can begin, including:

- Transportation, particularly as related to pipeline infrastructure
- Measuring, monitoring, and verification options and assurance of safety at the site
- Public outreach, education, and acceptance

Although many CO_2 sources are located conveniently to potential geological sequestration targets, including at the plant site, others are located far from known sinks; the CO_2 would need to be transported in order to dispose of it at a distance. This would be accomplished by converting the CO_2 to a liquid and transporting it by truck, railroad tank car, or pipeline. Transporting by pipeline is the most suitable alternative where large volumes of CO_2 in continuous supply are concerned. CO_2 pipeline transportation is an established technology with an established regulatory framework that has been successfully operating in many parts of the world for more than 35 years, particularly in relation to EOR. There are at least 70 active CO_2 EOR projects currently operating in the U.S. alone that employ a variety of pipeline lengths, including one 505 miles long that has been operating since 1971. Therefore, the technology of CO_2 pipeline construction and maintenance is well understood and could be handled by companies with many years of experience at minimal risk.

The costs of transporting CO_2 are many, including siting of the transportation corridor (any permitting fees, acquiring rights-of-way), purchase of the pipeline materials, construction and installation, compression of the CO_2 at the source (and recompression along the pipeline right-of-way if necessary), dehydration equipment, and various maintenance costs. Based on data from the MRCSP Phase I report, the cost of pipeline construction, assuming approximately $800,000 per mile, breaks down as follows:

- $355,200 for labor
- $148,000 for materials
- $83,200 for rights-of-way and damages
- $213,600 for everything else

State government also has a role to play in pipeline transportation by encouraging multiple-use transportation corridors (rights of way) and, if necessary (but as a last resort), taking by eminent domain.

Measurement, Monitoring, Verification, and Safety

It is important that risks to health, safety, and the environment involved with sequestration be taken into consideration early in the planning process as these often affect public acceptance. Such risks will also drive the formulation of standards and regulatory frameworks required for geological sequestration. Risk in geological sequestration can be divided into two categories:

- Risk to the surface (transportation and injection) system
- Risk associated with CO_2 in geological reservoirs

Failure or leakage in either of these situations poses risks to the environment and public health. However, these are the same risks as those associated with natural gas storage, fluid injection for hydraulic fracturing purposes, fluid waste disposal, and other standard practices of injecting fluids into underground rock layers. Gas storage, in particular, utilizes most, if not all, of the same technology that will be needed for CO_2 transportation, injection, storage, and monitoring. The primary difference between the two is that gas storage operators need to be able to withdraw the gas readily during times of high demand, as opposed to keeping the gas in the reservoir for decades or centuries. As such, an entire industry has grown up around fluid transportation and storage since the early 1900s and is adept at assessing and ameliorating risks before a problem can occur. Most risks of CCS are manageable because they are all familiar risks to the oil and gas industry. Therefore, it would be imperative that any state-funded geological sequestration project involve the gas storage and transportation industry.

Regulation

The U. S. Environmental Protection Agency (EPA) has announced plans to develop and propose regulatory changes to the Underground Injection Control (UIC) program established by the Safe Drinking Water Act by the summer of 2008. The regulations will establish a clear path for geologic sequestration-term storage and are intended to ensure that there is a consistent and effective permit system under the Safe Drinking Water Act for commercial-scale geologic sequestration programs.

Public Outreach, Education, and Acceptance

Although at this time there is, in general, a low awareness of CCS among the American public, there is or will soon be a great need for helping the public understand the issue and to alleviate their fears. Concerned citizens who are aware of the concept of sequestration are likely to be more worried about risks from CO_2 leakage than to be concerned about the beneficial aspects of underground storage. Perceived risks may differ from actual risks, but both must be taken seriously as part of any state commitment to geological sequestration. NUMBY (Not Under My Back Yard) is likely to emerge as an issue that will need to be addressed by education because negative public perceptions and active opposition can effectively delay, increase costs to a prohibitive level, and/or prevent deployment of sequestration projects. For example, a recent California bill on CCS failed in committee because local environmental groups were concerned with risk issues such as the 1986 Lake Nyos (Cameroon) CO_2 disaster, which had nothing to do with power plants, pipelines, or sequestration projects. Therefore, understanding and addressing public concerns at an early stage is critical if public acceptance of CO_2 sequestration is to occur.

Public outreach could be handled through regional public meetings held at state parks or other public venues in Pennsylvania. Each would serve multiple purposes including:

- Identifying the key stakeholder groups in each region
- Building awareness in that portion of the population likely to be interested
- Providing for informed discussion of the issues
- Building a base of informed public

A sequestration project situated on state (public) lands will likely generate resistance once proposed. It is therefore imperative to build a stakeholder base early in the process, before a project begins, that consists of local and regional public officials, environmental groups, disaster preparedness organizations, and the general public. Invitations to the regional meetings could be addressed through press releases, announcements in the Pennsylvania Bulletin and agency newsletters, visits to local social organization and municipal council meetings, and official letters to environmental groups.

The regional public meetings should be designed to educate the attendees on the sequestration project from beginning (carbon capture) to end (monitoring), emphasizing both the benefits of carbon sequestration and the long history of low risk involved with underground fluid storage and transportation. Although some attendees may be well educated and environmentally aware, many citizens will not have the technical background to understand all of the geological and engineering aspects of a project. As such, meetings should be designed to present the project in easy to understand terms presented by people with excellent credentials who have expertise in the various scientific, technical, and regulatory fields that will be discussed. Each meeting will have to allow sufficient time for questions and answers. Public support will be essential to the success of a state-based sequestration project.

Annex 1: The Economics of Geological Sequestration

A summary of key points about the economics of geological sequestration from some recent studies are presented below.

1. **Midwest Regional Carbon Sequestration Partnership (MRCSP)[18]** – Estimated sequestration supply curve - includes cost of capture, compression to pipeline quality condition, transport via pipeline, and injection (including monitoring):

Cost range/tonne CO_2	Associated with:
\$0-\$25	Terrestrial sequestration and CCS with high-purity sources (ethanol, hydrogen, gas processing), plus EOR and ECBM.
\$25-\$32	Low-purity sources (power, cement plants) storing with ECBM.
\$32-\$46	High-purity sources in value-added formations and low-purity sources paired with ECBM/EOR.
\$46-\$63	**Low-purity sources (predominately coal-fired power plants) in non-value added formations.**
\$64-\$105	Low-purity sources of decreasing size/purity (e.g. small gas-fired power plants) storing at longer distances.

Components:
- Capture: \$0 to \$57 per ton (coal fired in \$30-\$40 range)
- Compression: \$6 to \$12 per ton
- Transport: \$0.20 to \$15 per ton
- Injection (including monitoring): -\$7 to \$12 per ton (negative cost = EOR, ECBM)

2. **National Energy Technology Laboratory (NETL)[19]**
- Estimates a 30% increase in cost of electricity with CC and IGCC (excluding storage) with current technology.

3. **MIT – "The Future of Coal"[20]**
- Carbon capture technology – 40% energy penalty, adds at least 2.7 cents to retail price of electricity.
- \$30/tonne is benchmark for carbon tax or cap/trade market for CCS to be economically competitive.
  - At \$30/tonne, coal, natural gas, nuclear, wind roughly cost-competitive.
  - Capture/compression - \$25/tonne
- Transportation/storage - \$5/tonne

[18] http://198.87.0.58/PhaseIReport.aspx
[19] http://www.netl.doe.gov/technologies/carbon_seq/FAQs/benefits.html
[20] http://web.mit.edu/coal/The_Future_of_Coal.pdf

- Need at-scale pilots at least 1MMT/yr.
- 1MT CO_2 = 12,500 barrels/day supercritical CO_2
  - 1MT/yr full-spectrum CCS project - $15M/yr for 10 years (plus cost of acquiring CO_2)
  - Public education and outreach, siting/monitoring and liability/accounting system needed.

2. Natural Resources Defense Council (NRDC) – CO_2 Capture[21]

Costs

- Today's off the shelf systems - production cost of electricity at coal plant with CCD @ 40% higher than conventional plant.
- Impact on average electricity prices of introducing CCD now will be very much smaller due to several factors.
  - Power production costs represent about 60% of the price for electricity; rest comes from transmission, distribution costs.
  - Coal-based power = just over half of U.S. power consumption.
  - With immediate start, CCD would be applied to only small fraction of U.S. coal capacity for some time.
  - Incremental costs of units equipped with CCD spread over entire coal -based power sector.
- Based on CCD costs available in 2005, NRDC estimates that low-carbon generation obligation large enough to cover all forecasted new U.S. coal capacity through 2020 could be implemented for @ 2% increase in average U.S. retail electricity rates.

[21] http://www.nrdc.org/globalWarming/coal/mit.pdf

Annex 2: Candidate CO_2 Suppliers for a Pilot Geological sequestration Project

1. Sunnyside Ethanol, LLC

- Sunnyside Ethanol, LLC is a Pennsylvania-based company created for the specific purpose of building and operating large-scale ethanol manufacturing facilities in the Commonwealth.
- Sunnyside proposes to construct an ethanol facility at the former Howe's Leather Company site in the town of Curwensville, Clearfield County that will produce approximately 80 million gallons per year from 30 million bushels of corn per year.
- The facility will consist of a $110 million ethanol plant, a $60 million power plant, and a $6.5 million CO_2 plant.
- Sunnyside plans to use more than 200,000 tons of "gob" or waste coal (sometimes referred to as "tailings") annually to power the cogeneration plant. This has the value-added benefit of helping clean up the environment contaminated with acid mine drainage (AMD).
- The CO_2 produced each year was earmarked for sale to the beverage industry. However, Sunnyside is also expecting to sequester CO_2 both terrestrially and geologically.
- The project is waiting for financial matters to settle, but the company expects to break ground early in 2008. Completion of the plant is scheduled for early 2010.
- Sunnyside also has plans for constructing an ethanol at a former industrial site in Aliquippa, Beaver County that would produce as much as 80 million gallons of ethanol per year by 2010, and has plans to build as many as five ethanol plants in Pennsylvania.

2. Commonwealth Renewable Energy, Inc.

- Commonwealth Renewable Energy, Inc. is a subsidiary of Anderson Group of Companies, Inc., an investment firm based in the Pittsburgh area.
- The company initially planned to construct an ethanol production facility at Sony Corp.'s former American Video Glass plant in Hempfield Township, Westmoreland County that would produce more than 200 million gallons of ethanol annually.
- The company has all of its planned ethanol production under contract to undisclosed customers.
- However, plans for construction have been delayed one year because subcontractors were backlogged with equipment orders. In addition, initial production goals have been reduced to120 million gallons by the fourth quarter of 2008, with an increase to 200 million gallons annually in 2009.
- The plant will need about 45 million bushels of corn annually, most of it from Pennsylvania growers.

3. BioEnergy International, LLC

- BioEnergy International, LLC, a privately-held biotechnology company headquartered in Norwell, MA, develops technologies for producing fuels and specialty chemicals from feedstocks and cellulose.

- BioEnergy is developing an ethanol facility in Houtzdale, Clearfield County designed to produce 108 million gallons of ethanol per year from biomass, especially from the cellulose components of agricultural wastes.
- The company plans to have this technology ready for commercial deployment in our ethanol plant by 2008.
- The company has received a commitment from Governor Edward G. Rendell and the Commonwealth of Pennsylvania for over $22 million in state investments to support the project, as well as an additional commitment for $5 million for the construction of a cellulosic pilot plant utilizing the company's proprietary technology.
- BioEnergy has a 5-year offtake/tolling agreement with a major oil company, an agreement that provides a natural hedge against commodity price fluctuation

4. **Duke Energy**
   - Proposing to build an IGCC plant in Fayette County
   - Looking for details on the geology for geological sequestration.

5. **Coal Gas Recovery LP gas processing plant**
   - Parent Company: RAG Pennsylvania Coal Holding Company, RAG Pennsylvania Services Corporation, Waynesburg, Greene County.
   - The company operates a coal-bed methane processing facility located in Whiteley Township, Greene County (approximately seven miles south of Waynesburg).
   - The facility receives CBM from both the Cumberland and Emerald mines and processes the gas to prepare for delivery to a public utility pipeline. Propane is used as an additive to enhance the BTU (heating) value of the CBM.
   - The processing facility removes impurities (CO_2 and water vapor mostly) from the CBM, making it pipeline quality and usable for energy needs.
   - Up to six electric compressors and 16 gas-fired engine-driven compressors are situated at mine openings to pull CBM from the mine and send it to the processing facility by pipeline.
   - The plant is capable of processing 5.75 million cubic feet (Mcf) of CBM per day. (equivalent to approximately 4.95 Mcf of pipeline quality natural gas), enough to heat 15,000 homes for a year.

Appendix C
Forestry Recommendations

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Forestry

Table 1. Summary List of Forestry Mitigation Options

	Mitigation Option	GHG Reductions ($MMtCO_2e$)			Net Present Value 2008–2020 (Million $)	Cost-Effective-ness ($\$/tCO_2e$)
		2010	2020	Total 2008–2020		
F2	Afforestation, Planting, and Regeneration	*Varies by scenario; see below*				
F3	Forest Management Strategies To Enhance Carbon Sequestration	*Varies by scenario; see below*				
F4	A) Wood for Heat and Power Generation B) Wood for Liquid Fuel Production	*Varies by scenario; see below*				
F5	Wood Products/Processes	*Varies by scenario; see below*				
F6	Urban and Suburban Forests	*Varies by scenario; see below*				

F2. Afforestation, Planting, and Regeneration

Mitigation Option Description

This option seeks to increase carbon stored in vegetation and soils through expanding the land base associated with terrestrial C sequestration. Establishing new forests[1] ("afforestation") increases the amount of carbon in biomass and soils compared to pre-existing conditions. Planting and afforestation can take place on land not currently experiencing other uses, such as abandoned mine lands (AML), brownfields, oil and gas well sites, marginal agricultural land, and riparian areas. In addition to planting forest cover, this policy option also includes consideration of planting short-rotation woody crops and warm season grasses on a variety of underutilized land cover types.

This analysis focuses on the C sequestration benefit of afforestation only, and does not include the multiple co-benefits of afforestation (water, habitat, etc.)

Mitigation Option Design

Scenarios: Increase C sequestration on land not being utilized (i.e., brownfields, AML, oil and gas well sites, marginal agricultural land, and riparian areas).

- Scenarios were designed for practicality, and include a scaled usage of available land in each land use category (25%, 50%, 100%) for establishing one or a combination of the four vegetation types (afforestation with typical PA forest cover, warm-season grasses, short-rotation woody crops, riparian buffers) appropriate for that type of site.
- **Timing:** Achieve goal level by 2020
- **Coverage of parties:** DCNR, BOF, DEP, Alliance for the Chesapeake Bay, The Chesapeake Bay Foundation, The Western Pennsylvania Conservancy, USDA Conservation Reserve Enhancement Program

Potential Implementation Mechanisms

Leverage/enhance Tree Vitalize program and state/federal/private partnerships described below under existing programs.

Continue support for ongoing deer management strategy.

Incentive programs for landowners; e.g., incentives to address property taxes, implemented at the County level, potentially using "carbon leasing" at about $2–$3/acre (estimate based on leasing rates for recreational uses).

Develop set of criteria for evaluating proposed projects involving afforestation of non-forested lands, to identify potentially suitable opportunities on certain marginal pasture,

[1] Native species should be considered wherever possible.

abandoned mine lands, riparian/highly erodible areas, etc. Consider criteria such as potential forest type and projected carbon values, landscape context (e.g., size, contiguity, connectivity), site history/current condition, and economic analysis (e.g., opportunity, conversion and maintenance costs, potential credit eligibility).

Related Policies/Programs in Place

Target Programs, Goals Support Full Implementation of These Programs

- TreeVitalize: seeks an $8 million investment in tree planting and care in southeastern Pennsylvania over a four-year period. Goals include planting 20,000 shade trees; restoring 1,000 acres of forests along streams and water protection areas; and training 2,000 citizens to plant and care for trees. DCNR initiated preliminary discussions with regional stakeholders in summer of 2003, appointed a Project Director in January 2004. Planning, assessment and resource development continued through 2004. Tree-planting activities began in fall 2004 and will continue through fall 2007. The regional Tree Tenders program was launched in 2005. Although TreeVitalize is not a permanent entity, the collaborations created and capacity built will continue to increase tree cover and promote stewardship in the region. A Steering Committee, composed of funding entities, county governments and major technical assistance providers, identify priorities and approve projects. Operational committees, composed of local planting partners, technical assistance providers and/or public agencies with expertise in tree planting, will implement projects, deliver education and technical assistance. Other Committees will be formed on an as needed basis. See: http://www.treevitalize.net/aboutus.aspx. DCNR is examining opportunities to expand the program to other areas of the Commonwealth.
- Statewide – there are numerous programs in place – USDA CREP (Conservation Reserve Enhancement Program – where USDA subsidized farmers to keep highly erodable acres in warm season grass – which may in fact be a significant source of bio-fuel in switchgrass. Pennsylvania uses Growing Greener II II funds to enhance federal cost share payments for installation of conservation practices. In addition to warm season grasses, the CREP program subsidizes riparian forest buffer practices. One cost-shared practice is the installation of streambank fencing to exclude livestock and allow for natural forest regeneration. Another practice was riparian forest plantings.
- The CREP program is key to the expansion of forested riparian buffers throughout the Ohio and Chesapeake Bay drainages. From October 1, 2005, through September 30, 2006, 1,293 CREP contracts were approved on about 24,006 acres. This included the installation of over 3,406 acres of forested riparian buffers and planting another 4,799 acres of native grasses.
- Other buffer initiatives include Tree Vitalize, Stream Re-leaf, the Chesapeake Bay Urban Tree Canopy Expansion Initiative, and a suite of initiatives offered under the guidance of cooperators, including the Alliance for the Chesapeake Bay, The Chesapeake Bay Foundation, The Western Pennsylvania Conservancy, and DEP watershed specialists. A watershed forester working in the CFM section coordinates

BOF efforts in riparian projects. BOF Service Foresters throughout the state work with landowners to implement watershed programs on private lands.

- Since 2000, this cooperative effort among state, federal and non-profit organizations has resulted in the restoration of over 2,100 miles of forested buffers in the Chesapeake Bay drainage alone.

Enabling Programs, Programs May Provide Relevant Information in Support of Implementation

- DEP Bureau of Abandoned Mine Reclamation develops plans for handling AML in Pennsylvania. Bureau of Forestry – in DER era had a program called Project 20 – mine land reclamation. http://www.depweb.state.pa.us/abandonedminerec/site/default.asp?abandonedminerec

Type(s) of GHG Reductions

Reduced carbon dioxide emissions and increased sequestration of carbon dioxide.

Estimated GHG Savings and Costs per $MtCO_2e$

- **GHG Reduction Potential in 2010, 2020 ($MMtCO_2e$):** Varies by scenario. See analysis, below.
- **Cumulative GHG Reduction Potential ($MMtCO_2e$, 2008–2020):** Varies by scenario. See analysis, below.
- **Net Cost per $MtCO_2e$:** Varies by scenario. See analysis, below.
- **Data Sources:**
  - USDA Forest Service (USFS) Methods for Calculating Forest Ecosystem and Harvested Carbon with Standards Estimates for Forest Types of the US, General Technical Report NE-343 (also published as part of the Department of Energy Voluntary GHG Reporting Program).
  - USFS Forest Inventory Analysis data, provided by the USFS for the PA Forestry Inventory and Forecast. The carbon density data are from the Pennsylvania State Forest Carbon Inventory (Jim Smith, USFS).
  - Walker et al. 2007. Terrestrial carbon sequestration in the Northeast: Opportunities and Costs, Part 3A: Opportunities for Improving Carbon Storage through Afforestation of Agricultural Lands.
  - Duffy, M.D. and V.Y. Nanhou. 2002. Costs of producing switchgrass for biomass in southern Iowa. in: Trends in new crops and new uses. 2002. J. Janick and A. Whipkey (eds.). ASHS Press, Alexandria, VA.
  - Niu, X. and Duiker, SW. 2006. Carbon sequestration potential by afforestation of marginal agricultural land in the Midwestern U.S. Forest Ecology and Management 223: 415–427.
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- Adler, P.R, Del Grasso, S.J. and W.J. Parton, 2007. Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems. Ecological Applications, 17(3): 675–-691.
- Heller, M.C, G.A. Keoleian, T.A. Volk, 2003. Life cycle assessment of a willow bioenergy cropping system. Biomass and Bioenergy 25:147–165.

- **Quantification Methods:**

The quantification for this option seeks to analyze the possible opportunities for planting different types of vegetation on various types of underutilized land in PA. Scenarios were designed for practicality, and to illustrate the potential benefits and costs of different options under various levels of implementation (Table F2-1).

Table F2-1. Summary of Scenarios Used for Quantification of Afforestation and Planting Benefits and Costs

Land Use Category	Vegetation Type	Total Acreage Available for Planting Between 2008 and 2020 (acres)
Abandoned Minelands	Afforestation	250,000
	Short-rotation woody crops	
	Warm-season grass (switchgrass)	
Brownfields	Afforestation	2,329
	Short-rotation woody crops	
	Warm-season grass (switchgrass)	
Oil and Gas Well Sites	Afforestation	3,250
Marginal Agricultural Land	Afforestation	2,915,843
	Short-rotation woody crops	
	Warm-season grass (switchgrass)	
Riparian Areas	Afforestation	N/A

N/A = not available.

The Sections below detail the methods and assumptions used for each of the vegetation types planted and the variety of land use types considered in this option.

A. GHG Benefit of Vegetation Types

A.1. Afforestation With Typical PA Forest Cover

Forests planted on land not currently in forest cover will likely accumulate carbon at a rate consistent with the accumulation rates of average forest in the region. Therefore, C sequestered by afforestation activities was assumed to occur at the same rate as C sequestration in average PA forest. Average C storage was found based on USFS GTR-NE-343 assuming afforestation activity with a forest type distribution of 50% Maple-Beech-Birch and 50% Oak-Hickory. For afforestation under Option F-2, a 25-year project period was assumed, such that the rate of forest C sequestration (in all forest C compartments, including soil, live and dead biomass, forest floor, understory, and downed wood) under afforestation projects was estimated at 5.02 t CO2e $acre^{-1}$ $year^{-1}$ (Table F2-2). Forests planted in one year continue to sequester carbon in subsequent years. Thus C storage in a given year is calculated as the sum of annual C sequestration on cumulative planted acreage.

Table F2-2. Forest Carbon Sequestration Rates (in units t CO2e/ acre) for Afforestation Activity (source: Smith et al. 2006, NE-GTR-343)

	tCO2e/ac (0 yr)	tCO2e/ac (25 yr)	tCO2e/ac/yr (average)
Oak-Hickory (NE-GTR-343 Table B-3)	62.0	191.8	5.2
Maple-Beech-Birch (NE-GTR-343 Table B-2)	80.0	201.7	4.9

In riparian buffers, the amount of carbon sequestration achieved over time was quantified using a carbon sequestration rate of 3.92 tCO2e/ac/year. To calculate this rate, average carbon densities for Elm/Ash/Cottonwood forests (obtained from the USDA Forest Service for the PA Inventory and Forecast) were divided by 35, based on the assumption of an average stand age of 35 years obtained from FIA data.

A.2. Biomass Crops: Switchgrass, Willow, and Hybrid Poplar

The analysis of the potential for GHG benefits due to planting biomass crops on underutilized land separated biomass crops into two categories: warm-season grasses (switchgrass) and short-rotation wood crops (SRWC), assuming an equal mix of willow and poplar. Since data about the two SRWC crops (willow and poplar) are often presented separately, their GHG benefits were analyzed independently first, and then a weighted average assuming an equal willow- poplar mix was used for building the scenarios.

For all of the biomass crops, net GHG benefit was calculated as the difference between avoided fossil fuel emissions (from substituting biomass crops for fossil-intensive energy sources) and the emissions from crop management activities. These steps were followed:

1. Quantify the expected yield (in million Btu) per acre of vegetation in PA.[2]

2. Convert expected yield (in mBTU per acre) to units of tCO2e avoided per acre of biomass crop grown. This expected yield per acre (in 10^6 Btu per acre) was used to calculate the expected avoided fossil fuel use from utilizing biomass as a primary energy source. This calculation assumes an existing fuel mix of equal parts oil, natural gas, and coal. Conversion factors were taken from the 2000 PA Inventory and

[2] Yield per acre for switchgrass and poplar comes from presentation made by Greg Roth, Penn State College of Agriculture, "Energy from Biomass & Waste Conference" September 2007. Yield for willow comes from Heller et al. (2003).

Forecast of Greenhouse Gas Emissions (see Table F4-1 for specific conversion factors for each of the three fuel types).

3. Subtract emissions attributed to management activity. Since energy is used to grow the biomass crops, this expected fuel switching benefit must be reduced by an amount equal to the energy inputs required to produce the crops. Energy input from agricultural machinery and fertilizer production was thus subtracted from this expected fossil fuel offset benefit, to achieve an overall GHG benefit in tCO_2e/acre/year (Table F2-3).

In the Scenarios analyzed here, it was calculated that each acre of switchgrass would achieve an overall GHG benefit of 3.5 tCO_2e/year. Each acre of SRWC, assuming an equal mix of willow and poplar, would achieve an intermediate benefit between the willow and the poplar estimates, for a total GHG benefit of 4.6 tCO_2e/year. Soil C sequestration is not considered in this analysis.

Table F2-3. Net GHG benefits of biomass crop production in PA

	Expected Annual Yield (MBtu/Acre)	Annual tCO_2e Offset/Acre	Annual tCO_2e Emissions From Management Activities	Net GHG Benefit (tCO_2e/Acre/Year)
Switchgrass[3]	54.1	3.5	0.027	3.5
Willow[4]	60.4	4.0	0.065	3.9
Poplar	82.0	5.4	0.092	5.3

The work of Adler et al. (2007), who used a modeling analysis to quantify the complete set of life cycle benefits of various biofuel crops, provides a comparison for these methods. Adler et al. (2007) considered all fuel usage, equipment use, harvesting and transport costs, and production emissions to quantify net GHG comparisons for biofuel feedstocks in PA, including corn, soybean, alfalfa, switchgrass, hybrid poplar, and reed canarygrass. Switchgrass and hybrid poplar were the most favorable of all of the crops considered by Adler et al. (2007): ethanol and biodiesel produced from these crops reduced life cycle GHG emissions by ~115% below the life cycle CO_2e emissions produced by gasoline and diesel. In their analysis, switchgrass produced a net GHG sink of around 2.9 tCO_2e/acre/year for biomass conversion to ethanol and around 5.9 tCO_2e/acre/year when used for biomass gasification for electricity generation.

[3] For switchgrass and hybrid poplar, yield data are from Greg Roth, Penn State University, as presented at "Energy from Biomass & Waste Conference" September 2007. Data on GHG emissions form management activities represents the sum of on-farm emissions from machinery and embodied energy in fertilizer, herbicide, and pesticide (Adler et al., 2007).

[4] For willow, yield data are from Heller et al. (2003), assuming 13.6 oven-dry tons per hectare per year. This was converted to Btu assuming a heat content of 10.977 million Btu per short ton of biomass (Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table10.html). Data on management emissions are from Heller et al. (2003).

Biomass yield is an important source of variation in these estimates: these results depend on expected yield, which can vary substantially from actual yield. Actual yield can change dramatically depending on species and site conditions. As yield increases, the expected GHG benefit increases dramatically as well.

A.2.a. Switchgrass

Switchgrass is a perennial warm-season grass, grown for decades on marginal lands not well suited for conventional row crops. It has been identified as a potential feedstock for cellulosic ethanol production, as well as for biomass gasification to produce electricity.

A.2.b. Short-Rotation Woody Crops

Short-rotation woody crops such as willow and hybrid poplar can be grown on most agricultural land that is capable of producing cultivated or hay crops, but practically they may be limited to the more marginal production lands, where they can be used to reduce soil erosion and compete economically. They can also have significant water and fertilizer demands, which make them costly to produce. SRWC are generally harvested during the dormant season on a 3- to 4-year cycle. Since they re-sprout vigorously after cutting, seven to eight harvests can be obtained from a single planting. Fertilizers may be applied in the spring following harvest, in an amount determined by site conditions (Sampson et al., 2007).

B. Land Areas Available for Afforestation and Planting

For each of the vegetation types analyzed, a scaled implementation of planting on 25%, 50%, and 100% of the land use category was considered. A gradual ramp-up was assumed, such that full implementation of each Scenario would be achieved in 2020.

B.1. Abandoned Minelands (AMLs)

With 250,000 acres of abandoned minelands statewide,[5] these sites provide a potential opportunity for carbon sequestration and biomass feedstock production[6]. Restoring abandoned minelands, however, can be challenging and very costly due to the need for site preparation because of uneven terrain and the legacy of their prior use. Three potential uses for AML were considered: afforestation with a typical PA forest cover mix (including Maple-Beech-Birch and Oak-Hickory), switchgrass production, and SRWC production.

B.2. Brownfields

The 389 brownfields in the state of PA comprise 2330 acres of land area.[7] Although many brownfields are remediated and used as commercial or industrial sites, they also offer potential space for C sequestration. Three potential uses for brownfields were

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[5] From PA DEP information: http://www.depweb.state.pa.us/abandonedminerec/cwp/view.asp?a=1308&q=454835. Accessed October 2007.

[6] See http://www.biosolidsinstitute.com/ and Toffey, W., Flamino, E., et al. (2007) Demonstrating Deep Row Placement of Biosolids in Coal Mike Land Reclamation.

[7] From EPA: http://www.epa.gov/brownfields/bfwhere.htm. Accessed October 2007.

considered: afforestation with a typical PA forest cover mix (including Maple-Beech-Birch and Oak-Hickory), switchgrass production, and SRWC production.

B.3. Oil And Gas Well Sites

Oil and gas well sites also occupy small ¼–½ acre sites around the state, totaling 250 acres of land area annually.[8] Because these sites are widely scattered and quite small, management activities on oil and gas well sites are probably not feasible. Only the afforestation scenario was explored for these sites.

B.4. Marginal Agricultural Land

Marginal agricultural land is restricted by various soil physical/chemical properties, or environmental factors, for crop production. Based on an analysis of the1992 USGS National Land Cover Dataset together with soil characteristics obtained from the NRCS STATSGO soil dataset, Niu and Duiker (2006) reported that marginal agricultural land area of in PA totaled 1.18 Mha (approximately 36% of all land area in the state). This land was placed in the "marginal agricultural land" category because of its combination of soil and land cover characteristics, and includes land with high water table, steep slopes (high erodability), shallow soils, stoniness, and low fertility. For this analysis, afforestation, SRWC, and switchgrass were considered on marginal agricultural land.

C. Economic analysis

Economic analyses of vegetation planting costs typically employ four categories: opportunity cost (of planting forest rather than another, potentially more lucrative land use), conversion cost, maintenance cost, and measuring/monitoring costs (Walker et al. 2007). For this analysis, opportunity cost was assumed to be zero because the land considered in each of the Scenarios is currently underutilized.

One-time costs of vegetation establishment include site preparation and vegetation planting. These costs are incurred in the year of planting, one time only. Ongoing costs of maintenance and monitoring are incurred annually on all acreage planted in all years of policy implementation. The assumed costs of site preparation, vegetation establishment, and ongoing maintenance for each site type and vegetation combination are given in Table F2-4.

[8] Personal communication, Ronald Gilius with J. Quigley and J. Jenkins, CCS, October 2007.

Table F2-4. Economic Costs of Site Preparation, Vegetation Establishment, Maintenance, and Monitoring for Vegetation Planting Scenarios in Option F-2

Land Use Type	One-Time Costs		Annual Costs	
	Site Preparation	Planting	Maintenance	Monitoring[9]
Abandoned minelands[10]				
Switchgrass[11]	$2,500.00	$99.26	$103.66	$29.00
SRWC[12]	$2,500.00	$1,000.00	$261.54	$29.00
Afforestation[13]	$2,500.00	$680.00		$29.00
Oil & gas well sites				
Afforestation		$680.00		$29.00
Marginal agricultural land				
Switchgrass		$99.26	$103.66	$29.00
SRWC		$1,000.00	$261.54	$29.00
Afforestation		$680.00		$29.00
Brownfields				
Switchgrass		$99.26	$103.66	$29.00
SRWC		$1,000.00	$261.54	$29.00
Afforestation		$680.00		$29.00
Riparian areas				
Afforestation		$680.00		$29.00

D. Summary

For each of the combinations of vegetation and land use category described in the Scenarios in Table F2-1, a phased implementation of planting vegetation on 25%, 50% and 100% of the available land in that category by 2020 was analyzed. Discounted costs to 2020 were calculated using a 5% discount rate. Net present value (NPV) is the sum of the discounted costs—in other words, the economic cost or benefit of implementing the option between 2008 and 2020, calculated in today's dollars. Levelized cost-effectiveness

[9] Monitoring costs are assumed to be $29/acre for all vegetation types, assuming 20-year project duration (Walker et al., 2007).

[10] Cost of site preparation is average for abandoned minelands in Clinch and Powell River Valleys in VA and TN, and includes site preparation with minimal compaction, establishment of an erosion barrier, and herbicide application (Kant and Kreps 2004, Table 2). This is the minimum cost, out of an estimated range from $2,500 to $10,500. Additional costs, such as soil amendments, or differences between assumed and actual costs will materially affect the analysis.

[11] One-time planting cost and ongoing maintenance cost for switchgrass from Duffy and Nanhou (2002), who measured the cost of switchgrass production in Iowa at $518.75/ha. This work estimates switchgrass production costs using producers' data as much as possible and incorporating their actual management techniques, including costs of planting, management, harvesting, and any inputs.

[12] One-time planting cost for SRWC is estimated to be slightly higher than the one-time planting cost for typical PA forest due to specialized planting requirements and equipment. Ongoing maintenance cost is calculated from estimate of $43–$52 per tons of willow delivered (Volk, SUNY-ESF Willow Biomass Project), assuming average production yield of 13.6 tons/ha.

[13] Cost of afforestation is per acre cost of planting $150, plus tree ($100), herbicide ($130), and fencing ($300) costs (Paul Roth, DCNR, personal communication).

is the NPV of a scenario divided by the cumulative GHG benefit of that scenario. This is expressed in \$/tCO_2e sequestered or avoided, and is intended to give a sense for the cost of each scenario standardized for its actual GHG benefit across numerous scenarios and options that vary in terms of overall cost and cumulative GHG benefit.

Summary results for afforestation, short-rotation woody crops, and switchgrass production on abandoned minelands, brownfields, oil and gas well sites, and marginal agricultural land are presented in Table F2-6.

E. Riparian buffers

This analysis combines projected acreage from the Tree Vitalize and CREP forest riparian establishment programs. It assumes that the Tree Vitalize (or similar) program will establish 250 acres/year along the Chesapeake Bay drainage between 2007 and 2010, to meet the total program goal of 1,000 acres. It assumes that the CREP will ramp up each year from 2007 to 2010 until achieving 3,500 acres in 2010, and will continue this rate through 2020. Annual carbon sequestration is based on forests planted that year and in prior years under the program. Table F2-5 summarizes acres of riparian forests established annually and cumulatively, and associated carbon sequestration each year through 2020.

Table F2-5. Carbon Sequestered From Establishing Riparian Buffer Forests in PA

Year	Forests Established Annually (acres)	Forests Established in Prior Years (acres)	Carbon Sequestered Annually ($MMtCO_2e$/year)
2007	1,125	0	0.004
2008	2,000	1,125	0.012
2009	2,875	3,125	0.023
2010	3,750	6,000	0.038
2011	3,500	9,750	0.052
2012	3,500	13,250	0.066
2013	3,500	16,750	0.079
2014	3,500	20,250	0.093
2015	3,500	23,750	0.107
2016	3,500	27,250	0.120
2017	3,500	30,750	0.134
2018	3,500	34,250	0.148
2019	3,500	37,750	0.161
2020	3,500	41,250	0.175
Total	44,750		1.212

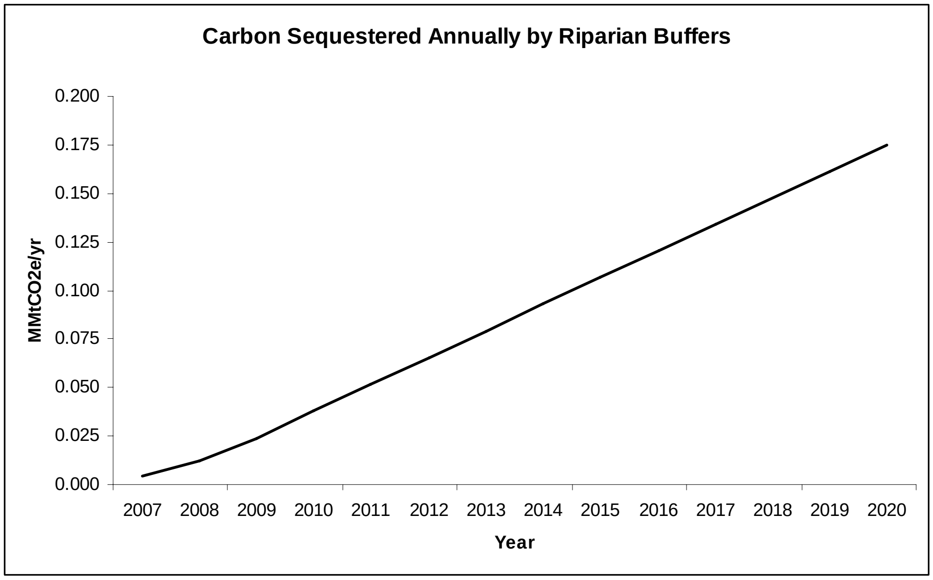
Table F2-6. Summary Results for Afforestation in Different Vegetation Types on Various Land Use Types in PA

Land Use Category	Total Acreage Available for Policy Implementation			Vegetation Type	Cumulative GHG benefit, 2008–2020 ($MMtCO_2e$)			Net Present Value 2008–2020 ($ million)			Levelized Cost-Effectiveness ($\$/tCO_2e$)
	25%	50%	100%		25%	50%	100%	25%	50%	100%	
Abandoned Minelands	62,500	125,000	250,000	Afforestation with typical PA forest cover	2.197	4.395	8.791	$158.1	$316.2	$632.5	$71.94
				Short-rotation woody crops (willow and poplar)	2.002	4.005	8.010	$239.3	$478.6	$957.1	$119.51
				Warm-season grass production (switchgrass)	1.535	3.070	6.140	$239.6	$479.3	$958.6	$102.11
Brownfields	582	1,165	2,330	Afforestation with typical PA forest cover	0.020	0.041	0.082	$0.4	$0.7	$1.5	$18.00
				Short-rotation woody crops (willow and poplar)	0.019	0.037	0.075	$1.1	$2.2	$4.5	$60.30
				Warm-season grass production (switchgrass)	0.014	0.029	0.057	$0.4	$0.7	$1.4	$24.87
Oil and Gas Well Sites	813	1,625	3,250	Afforestation with typical PA forest cover	0.029	0.057	0.114	$0.5	$1.0	$2.1	$18.0

Marginal Agricultural Land	728,961	1,457,922	2,915,844	Afforestation with typical PA forest cover	25.63	51.27	102.53	$461.4	$922.8	$1,845.8	$18.00
				Short-rotation woody crops (willow and poplar)	23.36	46.71	93.42	$1,408.2	$2,816.3	$5,632.7	$60.30
				Warm-season grass production (switchgrass)	17.90	35.81	71.62	$445.3	$890.7	$1,781.4	$24.87

Figure F2-1 shows annual carbon sequestration as a result of riparian buffer establishment over the time period 2007–2020, under full implementation of the goals outlined above.

Figure F2-1. Annual Carbon Sequestration in Riparian Buffers



Costs associated with establishing riparian buffer strips were assumed to be \$680/ acre, which is equivalent to the cost of afforestation with typical PA forest as described above. A summary of the total costs of buffer establishment under this option appears in Table F2-5. Note the estimate of annual C sequestration in Table F2-5 includes C sequestration by all riparian buffers established as part of this option from 2007 through 2020, since they will continue to sequester carbon each year after establishment. Costs are calculated only once for each acre, in the year of establishment. The NPV for establishment of riparian forests under this option is roughly \$21.9 million, with a levelized cost effectiveness of \$18.07/ tCO2e reduced.

Table F2-7. Summary of GHG Benefits and Economic Costs of Establishing Riparian Buffer Forests in PA

Year	Acres Established Annually	Discounted Cost	Annual C Sequestration ($MMtCO_2e$/year)
2007	1125	$765,000	0.004
2008	2000	$1,295,238	0.012
2009	2875	$1,773,243	0.023
2010	3750	$2,202,786	0.038
2011	3500	$1,958,032	0.052
2012	3500	$1,864,792	0.066
2013	3500	$1,775,993	0.079
2014	3500	$1,691,422	0.093
2015	3500	$1,610,878	0.107
2016	3500	$1,534,169	0.120
2017	3500	$1,461,114	0.134
2018	3500	$1,391,537	0.148
2019	3500	$1,325,273	0.161
2020	3500	$1,262,165	0.175
total	44750	$21,911,640	1.212

Key Assumptions and sources of uncertainty:

In the estimation of greenhouse gas savings and costs, some assumptions were made and a variety of literature sources were used.

In the calculation of C accumulation due to afforestation, the following sources of uncertainty exist:

- The assumption that afforested land will accumulate carbon at a rate consistent with average rates for the region from GTR-343.
- The assumption that the forest types involved in afforestation will be maple-beech-birch and oak-hickory, in equal proportions.
- The average C accumulation rate between stand age 0 and stand age 25 was used to calculate C storage rates. This is meant to capture the expected variability among young forests over the time period of analysis.
- Riparian buffers were assumed to belong to the cottonwood-elm-ash forest type group, and average stand age was assumed to be 35 years.

In the calculation of avoided C emissions due to the use of biomass crops, the following sources of uncertainty exist:

- It was assumed that biomass crops would displace oil, natural gas, and coal in equal proportion.
- It was assumed that plantations would distribute willow and poplar species in equal proportions.
- These numbers calculate benefits based on expected yield, which is likely to vary from actual yield.

In the calculation of the economic cost or benefit of each scenario, the following sources of bias/error exist:

- The assumption of zero opportunity cost because all land in the analysis is underutilized.
- The potential for lost crops/extra expenses due to factors not included in analysis (ie. fire, drought).
- The assumption that the cost of establishing a riparian buffer is equal to the cost of afforestation in a typical PA forest.

Gradual, incremental ramp-up of each option was assumed in all cases. If vegetation establishment occurs at a different rate, GHG benefits and expected costs could be quite different.

Each literature value used also has its own associated error and assumptions, which are usually described in the original source.

Key Uncertainties

Net GHG benefit of hybrid poplar versus willow.

Opportunity costs of afforestation on various types of land use.

Average age for elm-ash-cottonwood forest in PA.

Opportunity cost for land in riparian buffers (since this land may not be in active pasture or crop use even though it is adjacent to existing pasture or cropland acreage).

Limitations

The CMAG analysis did not consider fossil fuel substitution.

An analysis of afforestation or other biomass production/carbon sequestration on utility rights-of-way is beyond the scope of the CMAG analysis.

The CMAG afforestation analysis accounts for soil carbon sequestration, consistent with afforestation methodology presented in Smith et al. (2006) GTR-NE-343. Soil C sequestration is not accounted for in the SRWC or switchgrass calculations. Some organic agricultural and silvicultural practices may sequester up to as much as 1 ton of carbon per year per acre.

Additional Benefits and Costs

Establishing riparian buffers has benefits for water quality, stream bank stabilization, and wildlife habitat.

F3. Forest Management Strategies To Enhance C Sequestration

Mitigation Option Description

This option addresses the potential for increasing carbon stocks in forests through changes in management practices on existing public and private forestland. Examples are practices that increase tree density, enhance forest growth rates, alter rotation times, or decrease the chances of biomass loss from fires, pests, and disease. Increasing the transfer of biomass to long-term storage in wood products can also increase net carbon sequestration, provided a balance is maintained such that enough biomass remains on site as residues to serve as nutrient inputs to the forest. Practices may include management of rotation length, density and ecosystem health, and sustainable use of wood products. In addition, encouraging regeneration of existing forests through stocking/planting and restoration practices (e.g., soil preparation, erosion control, etc.) can increase carbon stocks above baseline levels and ensure conditions that support forest growth, particularly after intense disturbances.

Land participating in a certified management program is eligible to generate offset credits[14]. This option focuses on enhancing C storage in existing forests through restocking.

Biomass will be generated as part of this option, which can then be used to produce energy that offsets fossil fuel burning. This is accounted for in option F-4, which seeks to quantify the effects of a potential increase in biomass supply (due to thinning, capture of natural mortality, or harvest of poorly stocked stands, for example) on C emissions due to fuel switching.

Mitigation Option Design

- **Sequester more carbon through sustainable forest management** (not quantified)
- **Restock understocked land**
  - Scenario 1: Restock 100% of poorly-stocked land statewide by 2020.
  - Scenario 2: Restock 100% of poorly-stocked and 50% of moderately-stocked land statewide by 2020.
  - Scenario 3: Restock 100% of poorly- and moderately-stocked land by 2020.
- **Timing:** Reach goal level by 2020.
- **Coverage of parties:** DCNR Bureau of Forestry, private landowners, certification entities.

[14] Chicago Climate Exchange (CCX) – Forestry Contracts - http://www.chicagoclimatex.com/content.jsf?id=242

Potential Implementation Mechanisms

Full implementation of the Regeneration Fund at past levels.

New markets for small diameter wood could provide additional incentives (e.g., if more thinnings are directed into bioenergy uses.) [Links to Option F4]

Incentive programs to generate enough mid-rotation income; tax breaks; cost sharing; performance measures; forest management statute (may be feasibility issues).

Ensure an appropriate amount of the State Forest System is under active forest management, resulting in improved forest health and productivity.

Continue timber sales and continue/enhance management activities on State Forests that provide a reliable supply of timber for production of wood products, including low grade and residue material to support biomass energy production, where developed.

Provide funding or tax incentives to encourage private forest landowners to improve regeneration and stocking on their land.

FIA data may be used to estimate the technical potential of this option by identifying candidate lands. Feasibility should be used to score potential lands. Analysis should take into account varying levels of impacts due to insects and disease and deer browsing.

Related Policies/Programs in Place

Target Programs, goals support full implementation of these programs

- **Regeneration Fund:** (Act 601) $2–$3 million reinvested annually from timber sale receipts into projects which directly influence the successful regeneration/rehabilitation of SFL acres There are two types of projects associated with this program: 1.) Traditional—these are associated with current or future timber sale activity. 2.) Rehabilitation—these are not associated with timber sales and address non-stocked/understocked lands as a result of weather events, fire, or previous regeneration challenges. Activities can be found in Appendix C of the BOF Silviculture Manual (http://intraforestry/FAS/SFM/manual.htm). Activities include deer exclosures, treating interfering vegetation, fertilization, tree planting. The DCNR BOF, on average, reinvests 10% of timber sale receipts annually.

  White pine planting has been probably the most successful endeavor to supplement current understocked buffer areas or in young forest stands with partial natural regeneration. This is occurring on at least 1,500 acres annually

Enabling Programs, programs may provide relevant information in support of implementation

- **BOF Continuous Forest Inventory (CFI):** Permanent intra-bureau section which maintains permanent plot data collection within the SFL system multiple monitoring purposes http://www.dcnr.state.pa.us/forestry/sfrmp/docs/Manual%20of%20Biological%20Resources.pdf

- **BOF Division of Forest Fire Protection:** The Division of Forest Fire Protection is responsible for the prevention and suppression of wildfire on the 17,000,000 acres of wildland throughout the Commonwealth. The division maintains a fire detection system and works with fire wardens and volunteer fire departments to ensure that they are trained in the latest advances in fire prevention and suppression. The division also enters into partnerships with other state and federal agencies to share knowledge and resources. The division contains two sections: http://www.dcnr.state.pa.us/forestry/ffp/index.aspx
    - *Wildfire Operations Section*—The Wildfire Operations Section is responsible for fire suppression, surveillance and operations of contract aircraft. It provides support for field personnel. It is also responsible for the processing and collection of all fire claims and for providing trained fire suppression personnel to other states during wildfire emergencies.
    - *Wildfire Services Section*—The Wildfire Services Section is responsible for the enhancement of public safety and awareness in wildfire prevention through education, enforcement activities and the development of new fire technology. The section conducts special investigations throughout the Bureau as assigned. The section coordinates the distribution of federal funds and equipment to local fire fighting forces and acquires federal excess property to supplement Bureau fire equipment. The section also maintains warehouse operations.
- **BOF Division of Forest Pest Management:** The Division of Forest Pest Management is responsible for the protection of all forestland in the state from diseases, insects and other forest pests. The division's objective is to manage the health of the Commonwealth's forests in a manner that will limit forest value losses. http://www.dcnr.state.pa.us/forestry/foresthealth.aspx
    - *Forest Health Section*—The Forest Health Section is responsible for surveying, evaluating and monitoring insect and disease related forest influences. Various projects are implemented for the prevention, detection, diagnosis, investigation and evaluation of forest pest problems.
    - *Forest Pest Suppression Section*—This section is responsible for statewide forest pest suppression projects that involve the use of biological control agents or pesticides on State lands and forested residential lands. The section develops forest pest information and technology development and transfer.
- **USFS Forest Stewardship Program:** Promote the development of Stewardship Plans (10-year forest management plans) for private forestland. Bureau wide—delivered mainly by district located Service Foresters. Policy and cost coding procedures administered through the CFM Section. http://www.fs.fed.us/spf/coop/programs/loa/fsp.shtml
- BOF promotes wood utilization recovery per FSC (Forest Stewardship Council) standards and guidelines http://www.fscus.org/images/documents/2006_standards/app_4.2_NTC.pdf
- **Information on Harvest Schedules:** directly relating to rotation length. Extended rotation lengths were a key component of the HAM, per the SFRMP: 25% of the

multiple resource zone will be 80 years or older; 12% will be over 100 years or older; 5% will be 120 years or older. Please see http://www.dcnr.state.pa.us/forestry/sfrmp/silviculture.htm#allocation for more details.

- **20/24 Year Assessments—**BOF program where inventory plots are taken by district management foresters on previously harvested areas 20 or 24 years following harvest. This is species dependent, with northern hardwoods assessed at 20 and oak types at 24 which relates to the ecological progression of forest stands by species type and is termed forest stand dynamics. This time period is aimed to capture the conditions present when a stand is shifting from the "stand initiation phase" to the "stem exclusion" phase, meaning the vertical structure of the stand is probably close to established and an assessment will reveal if the stand has regenerated successfully and can be considered fully stocked.

Type(s) of GHG Reductions

Reduced carbon dioxide emissions and increased sequestration of carbon dioxide.

Estimated GHG Savings and Costs per $MtCO_2e$

- **GHG Reduction Potential in 2010, 2020 ($MMtCO_2e$):** Varies by scenario. See analysis, below.
- **Cumulative GHG Reduction Potential ($MMtCO_2e$, 2007–2020):** Varies by scenario. See analysis, below.
- **Net Cost per $MtCO_2e$:** Varies by scenario. See analysis, below.
- **Data Sources/References:**
  - USFS Methods for Calculating Forest Ecosystem and Harvested Carbon with Standards Estimates for Forest Types of the US, General Technical Report NE-343 (also published as part of the Department of Energy Voluntary GHG Reporting Program).
  - Sohngen, B. et al., 2007. The Nature Conservancy Conservation Partnership Agreement Part 4: Opportunities for Improving Carbon Storage and Management on Forest Lands.
  - Managed Forests in Climate Change Policy: Program Design Elements. Sampson, Ruddel & Smith. 2007 http://www.safnet.org/managedforests_final_12-14-07.pdf
  - Sterner, Stephen L. 2007. Commonwealth of Pennsylvania, Department of Conservation and Natural Resources, Bureau of Forestry, Resource Inventory & Analysis Section. Analysis of First 5-Year Continuous Forest Inventory Cycle.
  - The Pennsylvania Woodlands' Timber Market Report, Pennsylvania State University. Third quarter 2007 stumpage prices, http://www.sfr.psu.edu/TMR/TMR.htm.
- **Quantification Methods:**

Restock understocked forest

Forests that are not fully stocked do not grow as quickly as forests in fully stocked stands. This option seeks to quantify the costs and benefits of restocking timberland acreage that is currently in an understocked condition in PA (timberland is defined by the USFS as land that is capable of producing >= 20 ft^3/acre/year of industrial wood). The total acreage in PA timberland currently understocked is given in Table F3-5 (from USFS Forest Inventory and Analysis Unit, 2004). The scenarios developed for use in this option are described in Table F3-6.

Table F3-5. Acreage of Timberland by Stocking Class in PA (FIA, 2004)

Stocking Class	Area (Thousand Acres)	Proportion of Timberland Area
Poor	1,320	8%
Moderate	5,565	34%
Full	8,586	52%
Overstocked	989	6%
Total	16,460	

Table F3-6. Scenario Design for Option F-3b, Restocking Understocked Forest Land

	Annual Acreage Restocked (acres/year)		Total Acreage Restocked Annually (acres)	Proportion of All Timberland Restocked 2008–2020
	Poorly Stocked	Moderately Stocked		
Scenario 1: 100% of poorly-stocked land	101,523	0	101,523	19%
Scenario 2: 100% of poorly- and 50% of moderately-stocked land	101,523	214,039	315,561	60%
Scenario 3: 100% of poorly- and moderately-stocked land	101,523	428,077	529,600	100%

B.1. GHG Analysis

Since the most feasible approach for restocking involves harvesting understocked forest, then replanting a fully stocked forest, the quantification assumes that forests targeted under this option will first be harvested. Harvested volume is assumed to be made available for durable wood products. Using this assumption, the C in the understocked forest is assumed to be emitted in the year of harvest, except for that proportion expected to remain stored in long-term pools (such as durable wood products and in landfills) 100 years after harvest. Thus the difference between harvest emissions and long term storage is the net C loss due to harvest.

The biomass not stored in these long term pools is emitted to the atmosphere, either with or without energy production. If the harvested biomass is used for biomass energy, there could be an additional GHG benefit due to fuel switching via reduced demand for fossil fuel. This potential benefit was not quantified, but see F-4 for an analysis of the overall potential for biomass energy in PA.

The total live tree C in understocked forest was found as a function of the average volume in each of the stocking conditions. Volume data by stocking class were found from USFS FIA data (2004). Biomass values corresponding to these wood volume numbers were obtained from NE-GTR-343 (Table F3-7). It was assumed that 100% of the live tree biomass was lost due to harvest. It was assumed that no change took place in dead biomass C and soil C due to harvest.

Table F3-7. Live Tree Biomass in Understocked Stands in PA (from Smith et al., 2006)

	Poorly Stocked Volume (ft^3/acre)	Live Tree C Stock (tC/acre)	Notes	Moderately Stocked Volume (ft^3/acre)	Live Tree C Stock (tC/acre)	Notes
Maple-Beech-Birch	845.61	21.5	Table A2, corresponds to 25 years old, 830 ft^3/acre	1657.04	35.5	Table A2, corresponds to 45 years old, 1,702 ft^3/acre
Oak-Hickory	693.84	17.4	Table A3, corresponds to 15 years old, 779 ft^3/acre	1411.52	29.1	Table A3, corresponds to 25 years old, 1,368 ft^3/acre
Average		**19.45**			**32.3**	

See F-5 for detailed methodology to quantify the C stored in durable wood products 100 years after harvest. Results from that analysis suggest that of every cubic foot harvested from PA forests, 0.000708 tCO_2e are stored in long term pools (DWPs and landfills) 100 years after harvest. Thus, for this analysis the total cubic feet harvested during the restocking process was multiplied by 0.000708 to determine the C eventually stored in long term pools. This number was then subtracted from the total C in the understocked forest for acres cleared each year to estimate the net GHG impact of harvest (Table F3-8).

Table F3-8. Annual C Emissions Due to Harvest for Restocking

	Acres Harvested Annually (acres/year)		Vegetation C Stock Emitted (MMtC/year)	C Stored in DWPs (MMtC/year)	Net Annual Emissions Due to Harvest ($MMtCO_2e$/year)
	Poorly Stocked Stands	Moderately Stocked Stands			
Scenario 1	101,523	0	1.97	0.06	7.04
Scenario 2	101,523	214,039	8.89	0.29	31.5
Scenario 3	101,523	428,077	15.80	0.52	56.0

The targeted acreage is then assumed to be replanted in fully-stocked plantations, such that C sequestration in these acres occurs at a rate consistent with average C sequestration in these fully stocked stands in PA. Acres replanted in one year continue to sequester C in subsequent years, so the C sequestered in a given year is calculated as the sum of C stored on all restocked acres. Replanted forests are assumed to be an equal mix of spruce-balsam fir and white-red-jack pine stands, on a 50-year rotation. Expected C storage values are given in Table F3-9. Overall results of the analysis of C storage on replanted acres are given in Table F3-10.

Table F3-9. Forest Carbon Sequestration Rates in Conifer Forests

	MtC/acre (0 year)	MtC/acre (55 year)	MtC/acre/year (average)
Spruce-Balsam Fir	22.7	46.5	0.5
White-Red-Jack Pine	14.7	42.9	0.6

Table F3-10. C Storage on Restocked Acreage

Year	Scenario 1		Scenario 2		Scenario 3	
	Cumulative Planted Acreage	Annual C Storage ($MMtCO_2e$/year)	Cumulative Planted Acreage	Annual C Storage ($MMtCO_2e$/year)	Cumulative Planted Acreage	Annual C Storage ($MMtCO_2e$/year)
2008	101,523	0.2	315,562	0.6	529,600	1.0
2009	203,046	0.4	631,123	1.2	1,059,200	2.0
2010	304,569	0.6	946,685	1.8	1,588,800	3.0
2011	406,092	0.8	1,262,246	2.4	2,118,400	4.0
2012	507,615	1.0	1,577,808	3.0	2,648,000	5.0
2013	609,138	1.2	1,893,369	3.6	3,177,600	6.1
2014	710,662	1.4	2,208,931	4.2	3,707,200	7.1
2015	812,185	1.5	2,524,492	4.8	4,236,800	8.1
2016	913,708	1.7	2,840,054	5.4	4,766,400	9.1
2017	1,015,231	1.9	3,155,615	6.0	5,296,000	10.1
2018	1,116,754	2.1	3,471,177	6.6	5,825,600	11.1
2019	1,218,277	2.3	3,786,738	7.2	6,355,200	12.1
2020	1,319,800	2.5	4,102,300	7.8	6,884,800	13.1
Cumulative totals	**9,238,600**	**17.6**	**28,716,100**	**54.8**	**48,193,600**	**91.9**

The overall GHG impact of this option in a given year is calculated as the difference between emissions due to harvest and cumulative C storage on replanted acreage in that year (Table F3-11). The numbers in Table F3-11 represent net emissions rather than net GHG benefit, because the one-time loss due to harvest in a given year exceeds the C sequestration on cumulative planted acreage in all years of this analysis (2008–2020). If policy implementation is complete in 2020 and restocked land is allowed to continue to sequester C, it would take 29, 45, or 49 additional years, respectively, for C sequestration on restocked land to offset the one-time emissions from harvesting the understocked land in Scenario 1, 2, or 3.

Table F3-11. Net C Emissions From the Harvest/Replant Strategy for Achieving Fully Stocked Forest By 2020 ($MMtCO_2e$/Year)

Year	Scenario 1	Scenario 2	Scenario 3
2008	6.8	30.9	55.0
2009	6.7	30.3	54.0
2010	6.5	29.7	53.0
2011	6.3	29.1	52.0
2012	6.1	28.5	51.0
2013	5.9	27.9	50.0
2014	5.7	27.3	49.0
2015	5.5	26.7	48.0
2016	5.3	26.1	46.9
2017	5.1	25.5	45.9
2018	4.9	24.9	44.9
2019	4.7	24.3	43.9
2020	4.5	23.7	42.9
Cumulative total C emissions	**73.9**	**355.2**	**636.5**

B.2. Economic Analysis

Costs associated with this option include the costs of harvesting target acreage as well as the costs of replanting. Sohngen et al. (2007) estimate that the cost of harvest for a fully stocked forest is \$16.42/m^3, while the cost to harvest a poorly stocked stand is \$21.34/m^3 of volume. The "poorly stocked" figure of \$21.34/m^3 was used for this analysis. This is a one-time cost incurred in the year of harvest.

The cost of planting was estimated on a per acre basis at \$680/acre.[15] This includes the cost of planting (\$150/acre), plus seedlings (\$100/acre) and herbicide (\$130/acre). Fencing for deer exclusion totals \$300/acre. For comparison, Sohngen et al. (2007) report an average cost of forest planting of \$405/acre in the Northeast. Planting costs are often higher in Pennsylvania than in the region overall, due to the high cost of deer exclusion. Planting is also a one-time cost incurred in the year of harvest.

One-time revenue from harvested wood was calculated in the year of harvest using third-quarter 2007 stumpage prices from the Pennsylvania Woodlands Timber Market Report. This Report divides the State into four quadrants and reports prices paid per thousand board feet (MBF) by species. From this report, stumpage price for wood was averaged statewide by species, for an average price of \$311.86 per MBF. Annual revenue from harvest was subtracted from the annual cost of harvest to determine the net cost of Option F-3b under each Scenario.

Discounted costs for this option represent the one-time cost of harvest (per m^3 harvested) less revenue from harvested wood, plus the one-time cost of planting (per acre) for land treated in a given year, discounted to represent the economic cost of each scenario in

[15] Paul Roth, personal communication with J. Jenkins, October 2007.

today's dollars (using a discount rate of 5%). Levelized cost effectiveness is not estimated for this option, because the option results in a net C emission rather than avoided C emission or sequestration benefit. Total discounted costs for restocking understocked forests in PA are described in Table F3-12.

Table F3-12. Discounted Costs for Implementing the Harvest/Replant Strategy for Fully Stocking Understocked Acreage

Year	Scenario 1	Scenario 2	Scenario 3
2008	$114,226,567	$449,686,443	$785,146,318
2009	$108,787,207	$428,272,803	$747,758,398
2010	$103,606,864	$407,878,860	$712,150,856
2011	$98,673,204	$388,456,057	$678,238,910
2012	$93,974,480	$369,958,149	$645,941,819
2013	$89,499,504	$352,341,095	$615,182,685
2014	$85,237,623	$335,562,947	$585,888,271
2015	$81,178,689	$319,583,759	$557,988,830
2016	$77,313,037	$304,365,485	$531,417,933
2017	$73,631,464	$289,871,891	$506,112,317
2018	$70,125,204	$276,068,467	$482,011,731
2019	$66,785,908	$262,922,350	$459,058,791
2020	$63,605,627	$250,402,238	$437,198,849
Cumulative costs	$1,126,645,378	$4,435,370,544	$7,744,095,709

- **Key Assumptions:** See analysis, above.

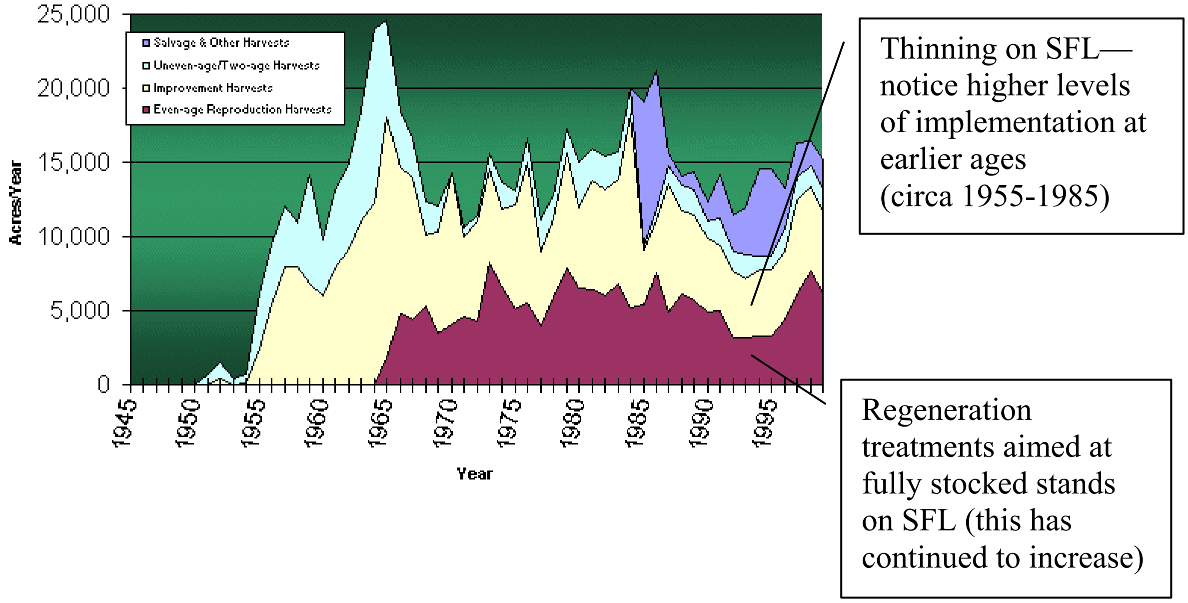
Feasibility Issues

Regeneration Fund and Restocking: Point for consideration – this is a long-term, expensive option. A lot of the variables contributing to understocked areas occurred over decades, and fixing/addressing them may take a similar time frame. Sometimes it's not a monetary issue, it's a personnel issue—cost-effective approaches are highly time dependant and competitive—planting crews often travel nation- if not continent-wide and often have narrow windows of opportunity.

Thinning and density management of managed stands where appropriate depending on site specific conditions

- Critical issues considered on a site by site basis include: competing vegetation, deer browsing impact, and stand age
- Per the Harvest Allocation Model, less than 10% of acres are scheduled for thinning/density management treatments (average of 14,000 acres scheduled annually translates into around 1400 acres receiving thinning/density treatments). This is directly related to the current age of the forest, where the opportunity to capture the benefits of such activities have passed. If our forest were of a younger age class there would be a much larger opportunity for such actions.

Figure F3-1. Annual Number of Acres Harvested From State Forest Lands



Limitations

An accounting for disposition of biomass – i.e. the GHG benefit of fuel switching, product substitution, long-term wood products using harvested wood – is beyond the scope of this analysis.

4a. Wood for Heat/Power Generation
4b. Wood for Liquid Fuel Production

Mitigation Option Description

Expanding use of forest biomass energy sources is being driven by market and policy forces. Biomass can be used to generate renewable energy in the form of liquid fuels (such as cellulosic ethanol, which is close to being market-ready), or through direct combustion to generate electricity, heat, or steam. Carbon in forest biomass is considered biogenic under sustainable systems; carbon dioxide emissions from biomass energy combustion are replaced by future carbon sequestration. Expanded use of biomass energy in place of fossil fuels results in net emissions reductions by shifting from high to low carbon fuels (when sustainably managed), provided the full lifecycle of energy requirements for producing fuels does not exceed the energy content of the renewable resource. Expanded use of biomass energy can be promoted through increasing the amount of biomass produced and used for renewable energy, and providing incentives for the production and use of renewable energy supplies.

Mitigation Option Design

- **Part A: Increase wood usage for heat and power generation**
  - Scenario 1: Increase wood utilization to 3 million tons/year by 2020
  - Scenario 2: Increase wood utilization to 6 million tons/year by 2020
- **Part B: Increase wood usage for ethanol production**
  - Scenario 1: All plants currently considering locating in PA at full capacity by 2015
  - Scenario 2: Double capacity of plants under consideration in PA by 2020
  - Scenario 3: Quadruple capacity of plants under consideration in PA by 2020
- **Timing:** Achieve goal level by 2020
- **Coverage of parties:** DCNR, DEP, USFS, utilities, private landowners

Potential Implementation Mechanisms

Energy Independence and Security Act of 2007 – Federal Renewable Fuels Standard

- Previous RFS was 5.4B gallons for 2008, rising to 7.5B by 2012.
- New law starts at 9B gallons in 2008 and rises to 36B gallons by 2022.
- Starting in 2016, all of the increase in the RFS target must be met with cellulosic ethanol and other biofuels derived from feedstock other than corn starch.

State lead by example: e.g., dedicated number of DCNR fleet vehicles running on biodiesel; use of biomass boilers for heat generation in DCNR facilities (i.e., state forest district offices or state park offices); the use of woody biomass for thermal energy production in new DCNR building construction (forest and park offices, lodges).

Assistance with building biomass energy facilities (tax incentives and financing).

Support tax incentives on the purchase of biomass energy equipment (for commercial and residential).

Continue management and timber sales that will make available woody material to support local biomass projects.

Continued timber sales and continued/enhanced management activities on State Forests that provide a reliable supply of timber for biomass energy production, where developed.

Related Policies/Programs in Place

Pennsylvania "Fuels for Schools - & Beyond" initiative - DCNR, DEP, PDA, NRCS, Resource Conservation and Development councils (RC&Ds), and Penn State University, among a much larger stakeholder group, are leading current activity in Pennsylvania to endorse a statewide biomass energy-use initiative promoting local renewable resources to provide reliable energy for Pennsylvania schools and businesses. The program has data on cost savings/carbon savings compared to displacing oil and natural gas. Program focuses on providing markets for low value wood products while providing lower cost biomass fuel alternatives.

DEP program areas—Expanded use of forest biomass feedstocks for electricity; Improved commercialization of biomass gasification and combined cycle; and production of liquid fuels from forest products (e.g., cellulosic ethanol).

Type(s) of GHG Reductions

Avoided carbon dioxide emissions due to fuel switching.

Estimated GHG Savings and Costs per $MtCO_2e$

- **GHG Reduction Potential in 2010, 2020 ($MMtCO_2e$):** Varies by scenario. See analysis, below.
- **Cumulative GHG Reduction Potential ($MMtCO_2e$, 2007–2020):** Varies by scenario. See analysis, below.
- **Net Cost per $MtCO_2e$:** Not quantified.
- **Data Sources:** PA I&F, Center for Climate Strategies (2006).
- **Quantification Methods:**

Part A. Wood for Heat and Power Generation

Currently, biomass plants using wood as a primary fuel generate about 320,000 MWH of electricity annually,[16] or about 0.22% of the total electricity used in PA in 2005.[17] Biomass can be co-fired with coal under certain circumstances as well, so a larger proportion of the PA electricity demand would likely be met if wood as a secondary fuel is included in the analysis of biomass use.

Two scenarios were quantified under option F-4a: 1) Increase wood use to 3 million tons annually, and 2) increase wood use to 6 million tons annually. Under each scenario, a linear ramp up to the goal level between 2008 and 2020 was assumed. In 2020, Scenario 1 meets 6.7% of statewide electricity demand with biomass fuels, and Scenario 2 reaches 13.4% of statewide demand with biomass fuels.[18]

To quantify the GHG benefit of fuel switching, the heat content of wood was assumed to be 9.961 million Btu per short ton.[19] This value was used to estimate the Btu contribution per unit of wood biomass, and then the annual increment in electricity Btu from wood biomass needed to reach the goal level for biomass usage in 2020 was calculated.

Btu produced using wood biomass would reduce the electricity produced using other fuels. The emissions avoided by producing electricity using wood were calculated using the emission factors in Table F4-1, which include emissions of CH_4, N_2O, and CO_2 and were calculated from the PA I&F.

Table F4-1. Emission factors for fossil fuels in PA

	Emission factors (tCO_2e/Btu)
Coal	93.815
Natural gas	52.455
Oil/petroleum	50.283
Wood	3.093

The GHG benefit of this option was quantified as the avoided GHG emissions from fuel switching for electricity production, assuming that avoided fuels were equally divided between coal, natural gas, and oil (Tables F4-2a and F4-2b).

[16] Personal communication, J. Sherrick with J. Jenkins, October 2007.

[17] Total electricity demand in PA (2005) is 148,273 thousand MWh (Energy Information Administration).

[18] Baseline electricity demand data for 2020 taken from PA I&F (CCS, 2006).

[19] From US Energy Information Administration, http://www.eia.doe.gov/cneaf/solar.renewables/page/trends/table10.html

Table F4-2a. Annual Electricity Production and Avoided Emissions To Reach Goal Level in Scenario 1 (Use 3 Million Tons of Biomass/Year By 2020)

Year	Additional Electricity Produced From Wood (BBtu/year)	Cumulative Electricity Produced From Wood (BBtu/ year)	Emissions From Wood (tCO_2e/year)	Emissions Avoided From Fossil Fuel (tCO_2e/year)	Net GHG Benefit (tCO_2e/year)	Net GHG Benefit ($MMtCO_2e$/year)
2008	2,533	2533	7,836	165,581	157,745	0.16
2009	2,533	5066	15,671	331,161	315,490	0.32
2010	2,533	7599	23,507	496,742	473,234	0.47
2011	2,533	10133	31,343	662,322	630,979	0.63
2012	2,533	12666	39,179	827,903	788,724	0.79
2013	2,533	15199	47,014	993,483	946,469	0.95
2014	2,533	17732	54,850	1,159,064	1,104,213	1.10
2015	2,533	20265	62,686	1,324,644	1,261,958	1.26
2016	2,533	22798	70,522	1,490,225	1,419,703	1.42
2017	2,533	25332	78,357	1,655,805	1,577,448	1.58
2018	2,533	27865	86,193	1,821,386	1,735,192	1.74
2019	2,533	30398	94,029	1,986,966	1,892,937	1.89
2020	2,533	32931	101,865	2,152,547	2,050,682	2.05
Cumulative totals		**35464**	**713,053**	**15,067,827**	**14,354,774**	**14.35**

Table F4-2b. Annual Electricity Production and Avoided Emissions To Reach Goal Level in Scenario 2 (Use 6 Million Tons of Biomass/Year By 2020)

Year	Additional Electricity Produced From Wood (BBtu/year)	Cumulative Electricity Produced From Wood (BBtus/ year)	Emissions From Wood (tCO_2e/year)	Emissions Avoided From Fossil Fuel (tCO_2e/year)	Net GHG Benefit (tCO_2e/year)	Net GHG Benefit ($MMtCO_2e$/year)
2008	5,066	5,066	15,671	331,161	315,490	0.32
2009	5,066	10,133	31,343	662,322	630,979	0.63
2010	5,066	15,199	47,014	993,483	946,469	0.95
2011	5,066	20,265	62,686	1,324,644	1,261,958	1.26
2012	5,066	25,332	78,357	1,655,805	1,577,448	1.58
2013	5,066	30,398	94,029	1,986,966	1,892,937	1.89
2014	5,066	35,464	109,700	2,318,127	2,208,427	2.21
2015	5,066	40,531	125,372	2,649,288	2,523,916	2.52
2016	5,066	45,597	141,043	2,980,449	2,839,406	2.84
2017	5,066	50,663	156,715	3,311,610	3,154,895	3.15
2018	5,066	55,729	172,386	3,642,771	3,470,385	3.47
2019	5,066	60,796	188,058	3,973,932	3,785,874	3.79
2020	5,066	65,862	203,729	4,305,093	4,101,364	4.1
Cumulative totals	**65,862**	**461,035**	**1,426,106**	**30,135,654**	**28,709,548**	**28.71**

Costs associated with fuel switching were not quantified, but are likely to be minimal if biomass is used to co-fire existing coal-based plants. Additional costs might include costs of changes in harvest practices or transportation.

Part B. Wood for liquid fuel production

Wood-based ethanol production is a developing technology. Currently, there are three producers potentially considering locating in PA[20] with varying feedstock needs (Table F4-3).

Table F4-3. Predicted Capacity and Feedstock Needs for Ethanol Plants Under Consideration in PA

Plant Number	Ethanol Produced (million gallons/year)	Biomass Feedstock Needed (thousand tons/year)	Gallons Ethanol Per Ton Biomass (Calculated)	Notes
1	25	325	76.9	Dry biomass; forest residue
2	40	495	80.8	25% moisture; feedstock needs estimated from 1500 tons/day assuming 330 days/year continuous operation
3	60	761		No feedstock information given
Totals	**125**	**1,581**		

The average number of gallons ethanol produced per ton of wood biomass (78.9 gallons ethanol/ton biomass) was calculated from advertised feedstock needs for Plants 1 and 2, which were the only two plants for which information on feedstock needs was available. This average was used to estimate feedstock requirements for Plant 3 (761 thousand tons/year). The total biomass needed per year for all three plants is 1581 thousand tons, or 1.58 million tons. This value (1.58 million tons for cellulosic ethanol producers currently considering a PA location) was included in the analysis as Scenario 1. Scenarios 2 and 3 discuss the implications of doubling and quadrupling this capacity, reaching 3.2 million tons/year and 6.4 million tons/year respectively, for production of cellulosic ethanol from wood feedstocks.

Current motor vehicle gasoline usage in PA is 123,808 thousand barrels annually, or 3.7% of total US consumption.[21] In Scenario 1, cellulosic ethanol would replace 1.6% of 2005 gasoline demand on an energy content basis, and 2.4% of 2005 demand if utilized for E10 gasoline. See discussion in B.1. below) . Scenarios 2 and 3 would meet 3.2% and 6.4%, respectively of 2005 fuel demand on an energy content basis, and 4.8% and 9.6%, respectively on an E10 basis. It is important to note that the biomass feedstock estimate needed to achieve Scenario 3—6.4 million tons/year—exceeds the highest estimates for sustainable biomass availability in PA.

[20] Personal communication, J. Quigley with J. Jenkins, CCS, October 2007.

[21] Energy Information Administration, 2005.

B.1. GHG Benefits

The GHG benefit of using cellulosic ethanol is the incremental benefit of substituting ethanol for fossil fuels. Emission factors for reformulated gasoline and cellulosic ethanol were taken from a General Motors/Argonne National Lab study.[22] These emission factors incorporate the GHG emissions during the entire life cycle of fuel production (e.g., for gasoline: extraction, transport, refining, distribution, and consumption; for ethanol: production, feedstock transport, processing, distribution, and consumption). These life cycle emission factors are referred to as "well-to-wheels" emission factors (Table F4-4).

Table F4-4. Well-to-wheels emission factors

Fuel	Emission Factor (g CO_2e/mile)
Reformulated gasoline	552
Cellulosic ethanol	154

Assuming an average fuel economy of 21.3 miles/gallon (MPG), the incremental benefit of using cellulosic ethanol over reformulated gasoline is 8477.4 g CO_2e per gallon of fuel. This MPG was used for both ethanol and reformulated (E10; i.e. 10% ethanol content, 90% gasoline) gasoline, as the incremental reduction in MPG when using ethanol for fuel is on average only about 1.5% lower than the average MPG when using reformulated gasoline.[23] Multiplying this by the volume of ethanol produced in each year gives the incremental GHG benefit of using cellulosic ethanol over traditional fossil fuel (Table F4-5).

Table F4-5. GHG Benefit of Substituting Cellulosic Ethanol for Reformulated Gasoline

	Scenario 1		Scenario 2		Scenario 3	
Year	Ethanol Produced (million gallons/year)	CO_2e Saved (MMt)	Ethanol Produced (million gallons/year)	CO_2e Saved (MMt)	Ethanol Produced (million gallons/year)	CO_2e Saved (MMt)
2008	16	0.13	31	0.26	63	0.53
2009	31	0.26	63	0.53	125	1.06
2010	47	0.40	94	0.79	188	1.59
2011	63	0.53	125	1.06	250	2.12
2012	78	0.66	156	1.32	313	2.65
2013	94	0.79	188	1.59	375	3.18
2014	109	0.93	219	1.85	438	3.71
2015	125	1.06	250	2.12	500	4.24
2016	125	1.06	250	2.12	500	4.24

[22] *Well-to-Wheels Analysis of Advanced Fuel/Vehicle Systems—A North American Study of Energy Use, Greenhouse Gas Emissions, and Criteria Pollutant Emissions*, General Motors, Argonne National Lab, and Air Improvement Resource, Inc., May 2005.

[23] Study conducted by the American Council on Ethanol (ACE) in 2005, found at: http://www.ethanol.org/pdf/contentmgmt/ACEFuelEconomyStudy_001.pdf

2017	125	1.06	250	2.12	500	4.24
2018	125	1.06	250	2.12	500	4.24
2019	125	1.06	250	2.12	500	4.24
2020	125	1.06	250	2.12	500	4.24
Cumulative total (2008–2020)		**10.07**		**20.13**		**40.27**

B.2. Economic Analysis

New manufacturing facilities are necessary to produce cellulosic ethanol. Therefore, the cost of this option is the cost of the new facilities. The government subsidy for 6 cellulosic ethanol plants recently funded by the Department of Energy ranged from $33 million to $80 million, with an average subsidy of $64.2 million.[24] Assuming a plant lifetime of 50 years, the average cost per year for one plant (in current dollars, regardless of production capacity) is $1.28 million. For this analysis, it was assumed that Scenario 1 would incur the full cost of three manufacturing plants, while additional plants built under Scenarios 2 and 3 would incur an incremental 50% and 100%, respectively, of the costs estimated under Scenario 1 (Table F4-6).

Table F4-6. Discounted Costs of Cellulosic Ethanol Production

Year	Scenario 1	Scenario 2	Scenario 3
2008	$3,850,000	$5,775,000	$7,700,000
2009	$3,666,667	$5,500,000	$7,333,333
2010	$3,492,063	$5,238,095	$6,984,127
2011	$3,325,775	$4,988,662	$6,651,550
2012	$3,167,405	$4,751,107	$6,334,809
2013	$3,016,576	$4,524,864	$6,033,151
2014	$2,872,929	$4,309,394	$5,745,859
2015	$2,736,123	$4,104,185	$5,472,246
2016	$2,605,832	$3,908,747	$5,211,663
2017	$2,481,744	$3,722,616	$4,963,489
2018	$2,363,566	$3,545,349	$4,727,132
2019	$2,251,015	$3,376,523	$4,502,031
2020	$2,143,824	$3,215,736	$4,287,648
Cumulative totals	**$37,973,519**	**$56,960,278**	**$75,947,038**

- **Key Assumptions:** See analysis, above.

Feasibility Issues

- Expanded use of forest biomass feedstocks for residential, commercial or industrial heating: BOF supports the utilization of biomass energy in sustainable scenarios. It is BOF's position that such scenarios will most likely be relatively small-scale endeavors for facilities such as schools, hospitals, or possibly state or federally administered facilities. Such technology is already employed by some entities in the sawmill industry and BOF supports expanded use within the industry.

[24] Department of Energy news release, http://www.energy.gov/news/4827.htm (February 2007).

Limitations

Analysis of the technology, costs/benefits, efficiency, and emissions characteristics of various alternative biomass energy applications, such as methanol or combined heat and power (CHP), is beyond the scope of the CMAG analysis. However, the associated co-benefit opportunities for small/community-scale CHP in PA, such as carbon mitigation and energy independence, are potentially substantial. While information is not currently available, ongoing activities (e.g. *Fuels for Schools - & Beyond*) offer the opportunity to gather significant amounts of additional information for cost-benefit consideration.

An analysis of emissions/costs/efficiency tradeoffs from transporting biomass feedstocks over various distances is beyond the scope of the CMAG analysis.

This analysis only considered wood harvested and not the residues from lumber industry processing.

In focusing attention on forest resources, the CMAG has not included in the analyses below any consideration or estimate of the availability of urban/suburban tree trimming and removals, clean construction residual lumber, and other clean wood sources which can augment supplies of available biomass. These sources may be substantial and worthy of consideration as potential feedstocks, but they are beyond the scope of this document.

F5. Wood Products/Processes

Mitigation Option Description

This option seeks to enhance the use and lifetime of durable wood products. Durable products made from wood prolong the length of time forest carbon is stored and not emitted to the atmosphere. Wood products disposed of in landfills may store carbon for long periods under conditions that minimize decomposition, especially when methane gas is captured from landfills (carbon originally stored in wood products becomes methane during decomposition). Substituting products made from wood for products with higher embodied energy in building materials can reduce life cycle GHG emissions from other products. This can be achieved through improvements in production efficiency, product substitution, expanded product lifetimes, and other practices. Increasing the efficiency of the manufacturing lifecycle for wood products will enhance greenhouse gas benefits. To quantify the categories for disposition of carbon in harvested wood, the analysis relied on USDA USFS Northern Research Station GTR-343, ***Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States.*** This methodology demonstrates the eventual destination of carbon from harvested wood in five broad categories: products in use, in landfills, emitted with energy capture, emitted without energy capture, and emitted at harvest.

Mitigation Option Design

- **Scenarios**: Enhance management activities and timber sales to provide a reliable supply of timber for durable wood products.
    - Scenario 1: Calculate disposition categories for 2006 estimate for level of statewide harvest (1.12 billion board feet/year) through 2020
    - Scenario 2: Calculate disposition categories for statewide wood harvest levels at 1.5 billion board feet/year through 2020
    - Scenario 3: Calculate GHG impact of current harvest level of 80 million board feet/year on PA State Forest Land through 2020
- **Timing:** See above
- **Coverage of parties:** DCNR, Pennsylvania Department of Transportation, PRDC, Pennsylvania Hardwoods Development Council, Pennsylvania State University, USFS and numerous private firms.

Potential Implementation Mechanisms

Updating LEED standards to recognize the carbon value of using wood building materials; support revising green building standards to give more credit for the utilization of wood products (including revising state building standards).

Promote state lead by example programs and promotions that greater utilization locally produced wood products in DCNR and other state construction projects.

Continue and enhance management activities and timber sales on State Forests that provide a reliable supply of timber for production of wood products.

Related Policies/Programs in Place

Enabling Programs, programs may provide relevant information in support of implementation

- Bureau of Facility, Design and Construction

Type(s) of GHG Reductions

Reduced carbon dioxide emissions and increased sequestration of carbon dioxide.

Estimated GHG Savings and Costs per $MtCO_2e$

- **GHG Reduction Potential in 2010, 2020 ($MMtCO_2e$):** Varies by scenario. See analysis, below.
- **Cumulative GHG Reduction Potential ($MMtCO_2e$, 2007–2020):** Varies by scenario. See analysis, below.
- **Net Cost per $MtCO_2e$:** Not quantified.
- **Data Sources:**
    - Sampson and Kamp, 2007. The Nature Conservancy Conservation Partnership Agreement Part 2: Recent Trends in Sinks and Sources of Carbon.
    - Smith et al., 2006. Methods for Calculating Forest Ecosystem and Harvested Carbon with Standards Estimates for Forest Types of the US, General Technical Report GTR-NE-343 (also published as part of the Department of Energy Voluntary GHG Reporting Program).
    - Miner, Reid. 2006. The 100-year Method for Forecasting Carbon Sequestration in Forest Products in Use. Mitigation and Adaptation Strategies for Global Change, 2006.
    - USDA Northeastern Forest Inventory and Analysis tables at: http://www.fs.fed.us/ne/fia/states/pa/
    - Lumber Production and Mill Stocks data from U.S. Census at: http://www.census.gov/industry/1/ma321t06.pdf
- **Quantification Methods:**

Increases in durable wood products that sequester carbon can be through improvements in production efficiency, product substitution, expanded product lifetimes, and other practices. For this analysis, three scenarios of harvest levels are presented (two which estimate state-wide harvest levels, and one which estimates harvest levels for PA State Forests). These harvest volumes can probably be achieved through more intensive management of forestland to ensure a reliable supply of high quality wood for durable wood products.

The three Scenarios quantified for this option are described in Table F5-1.

Table F5-1. Scenario Design for Option F-5: Wood Products and Processes

Scenario	Volume Harvested (billion board feet/year)
1. Current (2006) statewide volume harvest maintained through 2020	1.12
2: Statewide harvest increased by 34% through 2020	1.50
3. Current harvest on State Forest Land maintained through 2020	0.80

Carbon sequestration in harvested wood products (HWP) was calculated following guidelines published by the USFS in NE-GTR-343 (Smith et al., 2006). Details on each step of the analysis can be found in the Guidelines, following the methodology referred to as "Product-based estimates."

To quantify C stored in long-term products, forest harvest is used as a starting point. The methodology calculates the proportion of harvested wood that is diverted to each of four pools after 100 years: wood in use (i.e., building materials, furniture), wood in landfills (i.e., products that were previously in use and have been discarded), wood burned for energy capture, and wood that has decayed or burned without energy capture. The wood that has not been burned or decayed (i.e., the wood in the "in use" or "landfill" pools) is assumed to remain stored 100 years after harvest.

Most of the C stored in harvested wood products is emitted to the atmosphere over time. Because this method quantifies the amount of C in this year's harvest that is expected to remain

Stored (or "in use") for a defined period of time, rather than accounting instantaneously for the C stored in various products each year, this 100-year approach likely underestimates slightly the C stored over the 13-year implementation period of this analysis. Despite its conservatism, the 100-year method has the advantage of being simple and consistent, and has compared well with other accounting methods (Miner 2006).

The general methodology for all Scenarios in this option followed these steps:

1. Find the proportion of harvested volume that is in softwood or hardwood logs.
2. For each of the species types (hardwood and softwood), find the proportion of harvested volume in sawtimber and pulpwood.
3. Calculate tons C in harvested volume.
4. Project C stored in long-term storage pools 100 years after harvest for each Scenario.

The approach for each of the steps is described below.

1. The U.S. Census estimates that 1,121 million board feet were harvested from PA forests in 2006,[25] of which 1,055 million board feet (94%) was hardwood and 66 million board feet (6%) was softwood. These values were used directly for Scenario 1, and the total volume of hardwood and softwood harvested for Scenarios 2 and 3 was calculated assuming the same proportions.

2. The fraction of growing-stock volume in hardwood and softwood that occurs in each of the size classes (sawtimber and pulpwood) is given by NE-GTR-343. The distribution of harvest volume was assumed to follow the distribution of growing-stock volume presented in the Guidelines. An average mix of 50% Maple-Beech-Birch and 50% Oak-Hickory forest was assumed (Table F5-2).

Table F5-2. Factors Used to Apportion Harvest Volume Into Sawtimber and Pulpwood Classes for PA Forests

Forest type	Fraction of Softwood Volume That Is Sawtimber	Pulpwood (1 – Sawtimber)	Fraction of Hardwood Volume That Is Sawtimber	Pulpwood (1 – Sawtimber)
Maple-Beech-Birch	0.604	0.396	0.526	0.474
Oak-Hickory	0.706	0.294	0.667	0.333
Average	**0.655**	**0.345**	**0.597**	**0.403**

Source: Table 4, USDA NE-GTR-343.

3. The fractions above were used to determine the total harvest (millions of board feet) in each of the four categories (hardwood sawtimber, hardwood pulpwood, softwood sawtimber, softwood pulpwood) under each Scenario. These values were converted to m^3, and then multiplied by average specific gravity (from Table 4, NE-GTR-343) to find total C in harvested volume (Table F5-3).

Table F5-3. Carbon in Harvested Volume Under Three Scenarios in PA

	tC in Harvested Volume (tC/year)		
	Scenario 1: Current Statewide Harvest (1.12 billion board feet/year)	Scenario 2: 1.5 billion board feet/year	Scenario 3: 80 million board feet/year on SFL
Softwoods			
Sawtimber	19,306	25,833	1,378
Pulpwood	10,169	13,607	726
Hardwoods			
Sawtimber	390,555	522,598	20,056
Pulpwood	264,189	353,509	13,567
Total (MMt/year)	**0.684**	**0.916**	**0.036**

[25] From U.S. Census: http://www.census.gov/industry/1/ma321t06.pdf

4. Methods described in GTR-NE-343 were used to calculate the proportions of harvested C that were stored in each of the four disposition categories after 100 years (Table 4). These proportions were used to calculate the proportion of harvested C remaining in use or in landfills after 100 years.

Table F5-4. Proportion of Harvested C Remaining in Various Pools 100 Years After Harvest

	Disposition Factor
Softwoods–sawlogs	
In use	0.095
Landfill	0.223
Energy	0.338
Emitted w/o energy	0.344
Softwoods–pulpwood	
In use	0.006
Landfill	0.084
Energy	0.51
Emitted w/o energy	0.4
Hardwoods–sawlogs	
In use	0.035
Landfill	0.281
Energy	0.387
Emitted w/o energy	0.296
Hardwoods–pulpwood	
in use	0.103
landfill	0.158
energy	0.336
emitted w/o energy	0.403

Source: NE-GTR-343, Table 6.

Summary results for all three Scenarios, describing the total C stored in each long-term pool 100 years after harvest, are listed in Table F5-5.

Table F5-5. Total C Stored in Harvested Wood Products After 100 years for Three Scenarios

	Scenario 1: Current Statewide Harvest (tC/year)	Scenario 2: Increase Harvest to 1.5 Billion Board Feet (tC/year)	Scenario 3: Maintain Current State Forest Land Harvest (tC/year)
Softwoods-sawlog			
In use	1,834.03	2,454.10	130.88
Landfill	4,305.16	5,760.69	307.23
Softwoods-pulpwood			
In use	61.01	81.63	4.35
Landfill	854.16	1,142.95	60.95
Hardwoods-sawlog			
In use	13,669.42	18,290.93	701.96
Landfill	109,745.96	146,850.09	5,635.76
Hardwoods-pulpwood			
In use	27,211.50	36,411.47	1,397.38
Landfill	41,741.92	55,854.48	2,143.56
Total stored C 100 years post harvest (tC/year)	**199,423.20**	**266,846.38**	**10,382.12**
Total stored C 100 years post harvest ($MMtCO_2e$/year)	**0.731**	**0.978**	**0.038**

The cumulative result of the GHG savings from implementing these three scenarios over the full policy implementation period (2008-2020) are summarized in Table F5-6.

Table F5-6. Cumulative C Stored by Durable Wood Products Under Three Scenarios for Option F-5, 2008–2020

	2010 GHG Savings ($MMtCO_2e$/year)	2020 GHG Savings ($MMtCO_2e$/year)	2008–2020 GHG Savings ($MMtCO_2e$)
Scenario 1: 2006 Statewide harvest held constant (1.1 billion board feet/year)	0.73	0.73	10.97
Scenario 2: Statewide harvest increased to 1.5 billion board feet/year in 2008, maintained through 2020	0.81	1.00	12.96
Scenario 3: PA State Forest harvest held constant (80 million board feet/year)	0.04	0.04	0.57

- **Key Assumptions:**

Harvested wood volume reflects the growing-stock volume of PA forests.

PA forest composition was assumed to be 50% Oak/Hickory and 50% Maple/Beech/Birch.

Wood biomass assumed to contain 50% carbon (standard).

Key Uncertainties

The cost of durable wood products production is dependent upon various factors which make a cost analysis difficult and uncertain. An increase in C sequestration in durable wood products can be approached from various angles including: production efficiency, product substitution, expanded product lifetimes, and other practices. However, in this analysis only an estimate of GHG savings was provided for scenarios that increase supply of high quality wood for the manufacture of durable wood products.

A cost analysis for this option would depend upon how these harvest levels are met (i.e through afforestation or more intensive management of existing forest resources). Sections 2 and 3 of this report provide cost analyses for afforestation and forest management options.

Additional costs might include development of marketing materials and program administration meant to promote the use of durable wood products. These costs are not currently included in the analysis.

Limitations

By design, the CMAG quantification is relatively simple. Much more complicated analysis could be done here, incorporating transportation emissions, processing emissions, revenue from harvested products, etc.. Similarly, the analysis did not consider the opportunity cost if the wood was not harvested and decayed in the woods due to underutilization.

F6. Urban and Suburban Forests

Mitigation Option Description

Option F-6 seeks to increase carbon stored in urban forests, and thereby to reduce residential, commercial and institutional energy use for heating and cooling. Carbon stocks in trees and soils in urban land uses—such as in parks, along roadways, and in residential settings—can be enhanced in a number of ways, including planting additional trees, reducing mortality and increasing growth of existing trees, and avoiding tree removal (or deforestation). Forest canopy cover, properly designed, can also reduce energy demand by reducing building heating and cooling needs.

Mitigation Option Design

- **Scenarios:**

  Scenario 1: Increment existing tree cover in PA urban and suburban forests by 10% by 2020
  Scenario 2: Increment existing tree cover by 25% by 2020
  Scenario 3: Increment existing tree cover by 50% by 2020
- **Timing:** Achieve goals by 2020.
- **Coverage of parties:** DCNR, BOF, DEP, Alliance for the Chesapeake Bay, The Chesapeake Bay Foundation, The Western Pennsylvania Conservancy.

Potential Implementation Mechanisms

Leverage/expand Tree Vitalize Program

Consider a comprehensive approach to school tree planting

Provide incentives for private landowners to plant trees in residential areas

Related Policies/Programs in Place

Target Programs, Goals Support Full Implementation of These Programs

- Tree Vitalize: seeks an $8 million investment in tree planting and care in southeastern Pennsylvania over a four-year period. Goals include planting 20,000 shade trees; restoring 1,000 acres of forests along streams and water protection areas; and training 2,000 citizens to plant and care for trees. DCNR initiated preliminary discussions with regional stakeholders in summer of 2003, appointed a Project Director in January 2004. Planning, assessment and resource development continued through 2004. Tree-planting activities began in fall 2004 and will continue through fall 2007. The regional Tree Tenders program was launched in 2005. Although TreeVitalize is not a permanent entity, the collaborations created and capacity built will continue to increase tree cover and promote stewardship in the region. A Steering Committee, composed of funding entities, county governments and major technical assistance providers, identify priorities and approve projects. Operational committees, composed of local planting partners, technical assistance providers and/or public agencies with expertise in tree planting, will implement projects, deliver education and technical assistance. Other Committees will be formed on an as needed basis. See: http://www.treevitalize.net/aboutus.aspx. DCNR is examining opportunities to expand the program statewide.

Enabling Programs, Programs May Provide Relevant Information in Support of Implementation

- Urban and Community Forestry Programs – CFM Section – from the SFRMP - The Rural & Community Forestry Section provides professional forestry leadership and technical assistance promoting forestry and the knowledge of forestry by advising and assisting other government agencies, communities, landowners, forest industry, and the general public in the wise stewardship and utilization of forest resources. The section also coordinates the Bureau's conservation education efforts. The section also provides professional forestry leadership and technical assistance to rural communities and urban areas. Efforts include coordination with Penn State's regional urban foresters, Arbor Day activities, Tree City USA, Penn ReLeaf, the Harrisburg Greenbelt project, Municipal Tree Restoration program and the Urban & Community Forestry Council. http://www.dcnr.state.pa.us/forestry/rural/index.aspx

Major funding streams are through USFS State & Private Forestry through Urban Forestry Funds

- These support work at PSU
- Statewide Urban and Community Forestry Committee – Pennsylvania Community Forests
    - Which receives some funding from the Bureau of Rec/Con as well
    - Other smaller grants from utilities as well
- There is also currently a "NE PA Urban & Community Forestry Program" funded through the 10th congressional district—Rep. Sherwood (who is now out of office); this area does not include Scranton/Wilkes Barre–Williamsport largest city included in this area—$650,000 open grant
- City of Philadelphia Neighborhood Transformation Initiative—abandoned properties, vacant land being reclaimed as open space

Protection of urban forests from disease, fire, other risks; proper management of urban forests and street trees

- APHIS http://www.aphis.usda.gov/ gets involved in some of these issue—makes $ available to combat specific issues
- There is a federal bill being considered—H.R. 3933/S.941 the Suburban and Community Forestry and Open Space Program Act—$50 million annually in federal matching funds for assistance

Type(s) of GHG Reductions

Reduced carbon dioxide emissions and increased sequestration of carbon dioxide.

Estimated GHG Savings and Costs per $MtCO_2e$

- **GHG Reduction Potential in 2010, 2020 ($MMtCO_2e$):** Varies by scenario. See analysis, below.
- **Cumulative GHG Reduction Potential ($MMtCO_2e$, 2008–2020):** Varies by scenario. See Table above.
- **Net Cost per $MtCO_2e$:** –$604.87 for all Scenarios (negative cost indicates a net economic benefit).
- **Data Sources:**
  - Information about current numbers of trees in urban forest and annual C storage in urban trees in PA from Nowak et al., USFS, Northern Research Station, Urban Forest Effects on Environmental Quality State Summary data for Washington (http://www.fs.fed.us/ne/syracuse/Data/State/data_PA.htm).
  - Fossil fuel reductions through reduced demand for cooling and protection from wind from: McPherson and Simpson (1999). Carbon Dioxide Reduction Through Urban Forestry, USFS PSW-GTR-171.
  - Data on costs of tree planting and maintenance from Peper, PJ et al., 2007. New York City, New York Municipal Forest Resource Analysis. Center for Urban Forest Research, USFS Pacific Southwest Research Station.
  - Additional data on benefits of tree canopy in PA are from Nowak et al., 2007. Assessing Urban Forest Effects and Values: Philadelphia's Urban Forest. USFS Northern Research Station Resource Bulletin NRS-7.
- **Quantification Methods:**

This option quantifies the cumulative impact on carbon sequestration and avoided fossil fuel emissions of adding trees to existing canopy cover in PA. Specifically, Scenarios 1, 2, and 3 seek to increment the total number of trees in PA by 10%, 25%, or 50% by 2020. Currently PA contains 139 million urban trees: thus this option quantifies the effect of adding 13.9, 34.8, and 69.5 million trees total by 2020. The number of trees planted each year is constant, with the target number of trees planted by 2020.

GHG benefits are twofold: direct C sequestration by planted trees and avoided GHG emissions from strategic tree planting to reduce energy demand due to heating and cooling.

A. Direct C Sequestration in Urban Trees

A linear rate of increase in tree planting was assumed, with full scenario implementation occurring in 2020 for all 3 Scenarios. Annual C sequestration per urban tree is calculated as 0.006 tC/tree/year, based on statewide average data reported by the USFS. This is the average annual per-tree C sequestration value when the total estimated urban forest C accumulation in PA (863,000 tC/year) is divided by the total number of urban trees in PA

(139.0 million). Since trees planted in one year continue to accumulate C in subsequent years, annual C sequestration in any given year is calculated as the sum of C stored in trees planted in that year, plus the sequestration by trees that were planted in prior years.

B. Avoided Fossil Fuel Emissions

Offsets from avoided fossil fuel use for heating and cooling are the sum of three different types of savings: avoided emissions from reduced cooling demand, avoided emissions from reduced demand for heating due to wind reduction (this benefit is only available for evergreen trees), and enhanced fossil fuel emissions needed for heat due to wintertime shading. Calculations for avoided fossil fuel offsets are based on calculations presented by McPherson et al. in GTR-PSW-171 (Table F6-1). For this analysis, it is assumed that the trees planted are evenly split among residential settings with pre-1950, 1950–1980, and post-1980 homes, and that all planted are medium-sized, with 50% deciduous and 50% evergreen. These avoided emission factors assume average tree distribution around buildings (i.e. these fossil fuel reduction factors are average for existing buildings, but do not necessarily assume that trees are optimally placed around buildings to maximize energy efficiency). These factors are also dependent on the fuel mix (coal, hydroelectric, nuclear, etc.) in the region, and are thus likely to change if the electricity mix changes from its 1999 distribution.

Table F6-1. Factors Used To Calculate CO_2e Savings (MMtCO_2e/Tree/Year) From Reduced Need for Fossil Fuel for Heating and Cooling, and From Windbreak Effect of Evergreen Trees

Fossil Fuel Offsets: Evergreen Trees (Mid-Atlantic Climate Region)				
Housing vintage	shade-cooling	shade-heating	wind-heating	net effect
pre-1950	0.0168	–0.0315	0.1294	0.1147
1950–1980	0.0275	–0.0403	0.1555	0.1427
post-1980	0.0232	–0.0324	0.133	0.1238
Average	0.0225	–0.0347	0.1393	0.1271
Average (MMtCO_2e)				**0.127075**
Fossil Fuel Offsets: Deciduous Trees (Mid-Atlantic Climate Region)				
Housing vintage	shade-cooling	shade–heating	wind–heating	net effect
pre-1950	0.0260	–0.0320		–0.0060
1950–1980	0.0425	–0.0409		0.0016
post-1980	0.0358	–0.0329		0.0029
Average	**0.0348**	**–0.0353**		**–0.0005**
Average (MMtCO_2e)				**0.0632875**

Source: McPherson et al., 1999.

C. Overall GHG Benefit of Urban Tree Planting

Total GHG benefits are calculated as the sum of direct C sequestration plus fossil fuel offset from reduced cooling demand and wind reduction (Tables F6-2a, F6-2b, and F6-2c).

Table F6-2a. Overall GHG Benefit ($MMtCO_2e$/year) of Scenario 1: Increment Existing PA Urban Tree Canopy by 10%

Year	Trees Planted This Year	Trees Planted in Previous Years	GHG Sequestered	GHG Avoided	Overall GHG Savings
2008	1,069,385	0	0.02	0.07	0.09
2009	1,069,385	1,069,385	0.05	0.14	0.18
2010	1,069,385	2,138,769	0.07	0.20	0.28
2011	1,069,385	3,208,154	0.10	0.27	0.37
2012	1,069,385	4,277,538	0.12	0.34	0.46
2013	1,069,385	5,346,923	0.15	0.41	0.55
2014	1,069,385	6,416,308	0.17	0.47	0.64
2015	1,069,385	7,485,692	0.19	0.54	0.74
2016	1,069,385	8,555,077	0.22	0.61	0.83
2017	1,069,385	9,624,462	0.24	0.68	0.92
2018	1,069,385	10,693,846	0.27	0.74	1.01
2019	1,069,385	11,763,231	0.29	0.81	1.10
2020	1,069,385	12,832,615	0.32	0.88	1.20
Cumulative Totals		**13,902,000**	**2.22**	**6.16**	**8.37**

Table F6-2b. Overall GHG Benefit ($MMtCO_2e$/year) of Scenario 2: Increment Existing PA Urban Tree Canopy by 25%

Year	Trees Planted This Year	Trees Planted in Previous Years	GHG Sequestered	GHG Avoided	Overall GHG Savings
2008	2,673,462	0	0.06	0.17	0.23
2009	2,673,462	2,673,462	0.12	0.34	0.46
2010	2,673,462	5,346,923	0.18	0.51	0.69
2011	2,673,462	8,020,385	0.24	0.68	0.92
2012	2,673,462	10,693,846	0.30	0.85	1.15
2013	2,673,462	13,367,308	0.37	1.02	1.38
2014	2,673,462	16,040,769	0.43	1.18	1.61
2015	2,673,462	18,714,231	0.49	1.35	1.84
2016	2,673,462	21,387,692	0.55	1.52	2.07
2017	2,673,462	24,061,154	0.61	1.69	2.30
2018	2,673,462	26,734,615	0.67	1.86	2.53
2019	2,673,462	29,408,077	0.73	2.03	2.76
2020	2,673,462	32,081,538	0.79	2.20	2.99
Cumulative totals		**34,755,000**	**5.54**	**15.40**	**20.93**

Table F6-2c. Overall GHG Benefit ($MMtCO_2e$/year) of Scenario 3: Increment Existing PA Urban Tree Canopy by 50%

	Trees Planted This Year	Trees Planted in Previous Years	GHG Sequestered	GHG Avoided	Overall GHG Savings
2008	5,346,923	0	0.12	0.34	0.46
2009	5,346,923	5,346,923	0.24	0.68	0.92
2010	5,346,923	10,693,846	0.37	1.02	1.38
2011	5,346,923	16,040,769	0.49	1.35	1.84
2012	5,346,923	21,387,692	0.61	1.69	2.30
2013	5,346,923	26,734,615	0.73	2.03	2.76
2014	5,346,923	32,081,538	0.85	2.37	3.22
2015	5,346,923	37,428,462	0.97	2.71	3.68
2016	5,346,923	42,775,385	1.10	3.05	4.14
2017	5,346,923	48,122,308	1.22	3.38	4.60
2018	5,346,923	53,469,231	1.34	3.72	5.06
2019	5,346,923	58,816,154	1.46	4.06	5.52
2020	5,346,923	64,163,077	1.58	4.40	5.98
Cumulative totals		**69,510,000**	**11.08**	**30.79**	**41.87**

D. Cost Analysis

Economic costs of tree planting are calculated as the sum of tree planting and annual maintenance, including the costs of program administration and waste disposal. Economic benefits of tree planting include the cost offset from reduced energy use, as well as the estimated economic benefits of services such as provision of clean air, hydrologic benefits such as storm water control, and aesthetic enhancement.

Data were not available to assess the cost of tree planting specifically in PA communities. As a result, the cost of planting urban trees in PA is taken from Peper et al. (2007), whose analysis was conducted in New York City, NY. The average cost annualized cost per tree is estimated at $37.28, and includes planting, pruning, pest management, administration, removal, and infrastructure repair due to damage from trees.

Two types of data were available to quantify the economic benefit of planting urban trees. The first data source is the New York City analysis of Peper et al. (2007). Average annual cost savings of –$206.91 per tree from this work is the average of all trees in the city, and includes benefits of energy savings, improved air quality, improved stormwater quality, and improved aesthetics.

A second estimate of economic benefit per tree, specifically for Philadelphia, PA, was also used (Nowak et al., 2007). This analysis quantified the structural benefit of urban trees (i.e., replacement costs) as well as the annual functional benefits of urban trees (i.e., pollution abatement, energy savings). Total structural benefit of Philadelphia's 2.1 million urban trees was estimated at $1.8 billion. To determine the annual structural benefit of the urban tree canopy, this total citywide structural benefit was divided by 50 (the average lifetime of an urban tree). Annual functional economic benefits for the urban tree canopy were calculated as the value of pollution abatement ($3.9 million) plus the value of avoided energy costs ($1.19 million). The citywide structural and functional benefits were divided by the number of trees to estimate the annual economic benefit per tree in PA. From this source, the average annual (structural + functional benefit) per tree per year in PA was calculated at –$19.57.

For this analysis, –$206.91/tree/year and –$19.57/tree/year were averaged to estimate the economic benefits of planting urban trees (–$113.24/tree/year). While these values clearly diverge substantially from one another, the methods used to estimate economic benefits of non-market services such as clean air and water and pollution abatement, are inexact and variable. The value of –$113.24/tree/year is consistent with results obtained for similar analyses in other states.

Net economic costs for this option are calculated as the difference between costs of planting + maintenance and economic benefit realized by urban trees. Negative costs therefore refer to net economic benefits, where estimated benefits exceed overall costs. For this analysis, net economic benefit per tree was estimated at –$75.96/tree/year. Discounted costs were calculated assuming a 5% discount rate (Table F6-3). For all Scenarios, the cost-effectiveness of implementing F-6 is –604.85/tCO_2e.

Table F6-3. Discounted costs of implementing Scenarios 1–3

Year	Scenario 1	Scenario 2	Scenario 3
2008	–$81,228,673	–$203,071,683	–$406,143,365
2009	–$154,721,282	–$386,803,205	–$773,606,410
2010	–$221,030,403	–$552,576,007	–$1,105,152,015
2011	–$280,673,528	–$701,683,819	–$1,403,367,638
2012	–$334,135,152	–$835,337,880	–$1,670,675,759
2013	–$381,868,745	–$954,671,862	–$1,909,343,725
2014	–$424,298,605	–$1,060,746,514	–$2,121,493,027
2015	–$461,821,611	–$1,154,554,029	–$2,309,108,057
2016	–$494,808,869	–$1,237,022,173	–$2,474,044,347
2017	–$523,607,269	–$1,309,018,173	–$2,618,036,346
2018	–$548,540,949	–$1,371,352,372	–$2,742,704,743
2019	–$569,912,674	–$1,424,781,685	–$2,849,563,370
2020	–$588,005,140	–$1,470,012,849	–$2,940,025,699

Summary results of GHG benefits and net economic costs are shown in Table F6-4.

Table F6-4. GHG Benefits and Economic Costs of Three Urban Tree Planting Scenarios

	GHG Reduction Potential in 2010 ($MMtCO_2e$)	GHG Reduction Potential in 2020 ($MMtCO_2e$)	Cumulative GHG Reduction Potential 2008–2020 ($MMtCO_2e$)	Cost-Effectiveness ($\$/tCO_2e$)
Scenario 1: Add 10% to existing tree canopy cover	0.276	1.196	8.373	–$604.87
Scenario 2: Add 25% to existing tree canopy cover	0.690	2.990	20.933	–$604.87
Scenario 3: Add 50% to existing tree canopy cover	1.380	5.981	41.867	–$604.87

- **Key Assumptions:** Economic costs and benefits of urban tree cover. See quantification, above.

Additional Benefits and Costs

Potential energy savings from strategically planted shade trees, which would result in reduced energy needs and costs for heating and cooling.

Feasibility Issues

- Avoided deforestation: Local policies: There is not a statewide mechanism and the local ordinances are highly variable.
- Preservation of open space: Appears to be considerable variation in the definition of this term in local ordinances and between organizations—open space vs. green space. This may be better stated as "Preservation of urban canopy cover."
- Promotion of working forests: Not very common but does occur in some municipalities that have large park areas with merchantable species—some examples from around the state.
- Constructive use of biomass from cleared urban forests: Issues related to metal in urban trees; realization of value in light of other values in developer's scope; very local ordinances—zoning restrictions, etc.

Limitations

Assessing discrete opportunities for wood products and processes, e.g. substituting wood building materials for steel products, desirable changes in local building codes, LEED standards, and Commonwealth procurement rules is beyond the scope of the CMAG analysis.

The impact of state/federal tax and subsidy policies and other government programs on forestry is beyond the scope of the CMAG analysis.

A detailed analysis of short-rotation woody crops is also beyond the scope of the CMAG analysis.

Appendix D
Land Conservation Recommendations

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Table 1.

Summary List of Landscape Preservation Options

	Mitigation Option	**GHG Reductions ($MMtCO_2e$)**			**Net Present Value 2008–2020 (Million $)**	**Cost-Effective-ness ($\$/tCO_2e$)**
		2010	**2020**	**Total 2008-2020**		
LP-1	Forest Acquisition and Protection	*Varies by scenario; see below*				
LP-2	Reduce Forest Conversion to Developed Use	*Varies by scenario; see below*				

1. Forest Acquisition and Protection

Mitigation Option Description

This option seeks to quantify the carbon benefit of forestland conservation and its associated carbon stocks and sequestration potential through land acquisition by DCNR. (It is not intended to and does not capture the other multiple benefits of land conservation.) When forests are converted to other land uses, forest biomass is typically cleared and the carbon stored in that biomass is emitted through decay and combustion, and/or is transferred into wood products. Non-forested areas generally contain much lower amounts of biomass and associated carbon, and sequester less carbon on a per area basis than forests.

Mitigation Option Design

- Protect private forestland through direct acquisition or through various DCNR programs for open space preservation. Three alternative scenarios are analyzed for this option. Scenario 1 is based on full implementation of Growing Greener II, and Scenarios 2 and 3 are based on expansion of the program.
  - Scenario 1: Acquire 20,000 acres/year during 2008-2011.
  - Scenario 2: Acquire 20,000 acres/year every year during 2008-2020.
  - Scenario 3: Acquire 20,000 acres/year during 2008-2011, increase to 40,000 acres/year during 2012-2020.
- **Timing:** Varies by Scenario. See above.
- **Coverage of parties:** PA DCNR Bureau of Forestry

Potential Implementation Mechanisms

Develop set of criteria for evaluating proposed projects involving the protection of existing forestland to identify potentially significant carbon sequestration opportunities at low marginal costs and with associated environmental co-benefits. Consider using criteria such as forest type/age and related carbon values--current and projected, landscape context (e.g., size, contiguity, connectivity), threat of conversion, economic analysis (e.g., opportunity, conversion and maintenance costs, potential credit eligibility), stocking levels/regeneration rates, ecological values, etc. To the greatest extent possible, use data that are currently available (e.g., FIA, NRCS, etc.).

There is some potential applicability of the planned PA Map program, which will use periodic remote sensing (~ every three years) to detect land use/land cover change and could also be used estimate changes in net biomass (or ecosystem) productivity. (See also Related Policies/Programs in Place)

Consider enabling actions to reduce leakage (e.g., enabling actions), investigate ways to estimate and understand leakage issues, including improvements in data capabilities to track land use change.

Related Policies/Programs in Place

Target Programs, goals support full implementation of these programs

- DCNR Growing Greener II Bond Initiative – Funds will be used by DCNR to acquire development rights or where necessary acquire lands; award grants to municipalities and conservation organizations to acquire lands that are threatened by development; purchase easements to conserve privately owned working forests; and purchase buffers or inholdings to protect existing state park and forest lands and to acquire lands of significant ecological or recreational value. "Conserving Special Places" concept paper. Currently in an era of SFL expansion – goal is 20,000 acres a year based on current funding levels.

Enabling Programs, programs may provide relevant information in support of implementation

- DCNR – Conservation Landscape Initiative: Department level program targeting statewide landscapes for conservation efforts and focusing DCNR efforts on those areas.
- Developing an approach to refine geographic information system (GIS) infrastructure to support identifying the spatial distribution of these priorities statewide.
    - For SFL system this is accomplished and being refined with a current contract with the Sanborn Map Company to develop a robust Enterprise Information Management System (EIMS)

Types(s) of GHG Reductions

Avoided emissions from loss of carbon stocks and protection of annual carbon sequestration potential of forests.

Estimated GHG Savings and Costs per $MTCO_2e$

- **GHG reduction potential in 2010, 2020 ($MMtCO_2e$):** Varies by Scenario. See analysis, below.
- **Cumulative GHG reduction potential ($MMtCO_2e$, 2007-2010):** Varies by Scenario. See analysis, below.
- **Net Cost per $MtCO_2e$:** Varies by Scenario. See analysis, below.
- **Data Sources:** US Forest Service Methods for Calculating Forest Ecosystem and Harvested Carbon with Standards Estimates for Forest Types of the US, General Technical Report NE-343 (also published as part of the Department of Energy Voluntary GHG Reporting Program). Data provided by the USFS for the PA Forestry Inventory and Forecast; program costs provided by DCNR. Strong, T.F. 1997. Harvesting intensity influences the carbon distribution in a northern hardwood ecosystem. USDA Forest Service North Central Forest Experiment Station Research Paper NC-329.

- **Quantification Methods:**

Carbon savings from this option were estimated from two sources: (1) the amount of carbon that would be lost as a result of forest conversion to developed uses (i.e., "avoided emissions"); and (2) the amount of annual carbon sequestration potential that is maintained by protecting the forest area.

Analysis for each of these sources was conducted across three scenarios, each with four sets of assumptions about development threat. The three scenarios differ with regard to number of acres preserved per year (see Table LP1-1). In all scenarios, 50% of preserved forests are Oak-Hickory and 50% are Maple-Beech-Birch. These forest types were chosen because they are predominant in PA, each making up about 44% of total forest cover in PA (FIA).

Table LP1-1. Alternative Acreage Scenarios used to Calculate Carbon Savings

Scenario	Acres acquired per year
Scenario 1	20,000 in 2008-2011
Scenario 2	20,000 in 2008-2020
Scenario 3	20,000 in 2008-2011; increase to 40,000 in 2012-2020

Each scenario was calculated under four sets of assumptions regarding the threat level for development of PA forestlands. Assumption A is that 100% of land acquired under the program would have been developed if the program did not exist; Assumption B is that 50% of acquired land would otherwise have been developed; Assumption C is that 20% of the acquired land would otherwise have been developed; and Assumption D is that 10% of the acquired land would otherwise have been developed.

(1) Avoided Emissions

Carbon savings from avoided emissions were calculated using estimates of total standing forest carbon stocks in PA, provided by the USFS as part of the Forest Inventory and Forecast for PA (Table LP1-2).

Table LP1-2. Carbon Pools in Predominant PA Forests

Forest Carbon Pool	Oak-Hickory	Maple-Beech-Birch
	MtC/acre	MtC/acre
Live tree	35.8	36.7
Standing dead tree	1.6	2.6
Understory	0.7	0.7
Down dead wood	2.4	2.6
Forest floor	3.3	10.8
Soils	21.5	28.1
Total	65.3	81.5

Loss of forests to development results in a large one-time surge of carbon emissions. In this case, it was assumed that 100% of the vegetation carbon stocks would be lost in the event of forest conversion to developed uses, with no appreciable carbon sequestration in soils or biomass following development. The soil carbon loss assumption is based on a study that shows about a 35% loss of soil carbon when woodlots are converted to developed uses (Austin, 2007). A comparison of data from the American Housing Survey[1] with land use conversion data from the Natural Resources Inventory (NRI) suggests that, on average, two thirds of the land area in a given residential lot is cleared during land conversion. Thus, it was assumed that, during forest conversion to developed use, 100% of the forest vegetation C and 35% of the soil C would be lost on 67% of the converted acreage.

To estimate avoided emissions, the total number of acres protected in a year was multiplied by the estimate of one-time C loss from biomass and soils due to development. In Maple-Beech-Birch forests, this estimated C loss was 56.2 t C per acre; in Oak-Hickory forests, the estimated C loss was 49.2 t C per acre. In both forest types, this estimate of C loss due to development is calculated as the sum of 100% of average standing vegetation C stocks (live + dead) and 35% of average soil C stocks (forest floor + mineral soil). This overall avoided C emissions estimate was then converted to million metric tons of CO2 equivalents (MMTCO2e) (Table LP1-3).

Only the acres that would have otherwise been converted to forests are considered in the avoided emissions calculation: in this way, the results are sensitive to the four sets of assumptions about conversion threat. Table LP1-3 shows the annual and total acres acquired by the program and associated avoided emissions that would be generated under each of the three scenarios, and for each of the four alternative assumptions regarding level of development threat. While some of the biomass lost during clearing might be used for bioenergy production, this effect was not quantified in the analysis of LP-1.

Table LP1-3. Emissions Avoided by Protecting Forest Land in PA.

	Years	**Acres acquired**	**Avoided emissions (MMtCO2e)**			
			Assumption A (100% development threat)	*Assumption B (50% development threat)*	*Assumption C (20% development threat)*	*Assumption D (10% development threat)*
Scenario 1	2008-2011	20,000/yr	3.19/yr	1.59/yr	0.64/yr	0.32/yr
	2012-2020	0/yr	0/yr	0/yr	0/yr	0/yr
	Total	80,000	12.74	6.37	2.55	1.27
Scenario 2	2008-2011	20,000/yr	3.19/yr	1.59/yr	0.64/yr	0.32/yr
	2012-2020	20,000/yr	3.19/yr	1.59/yr	0.64/yr	0.32/yr
	Total	260,000	41.41	20.70	8.28	4.14
Scenario 3	2008-2011	20,000/yr	3.19/yr	1.59/yr	0.64/yr	0.32/yr
	2012-2020	40,000/yr	6.37/yr	3.19/yr	1.27/yr	0.64/yr
	Total	440,000	70.07	35.04	14.01	7.01

[1] US Census, http://www.census.gov/hhes/www/housing/ahs/ahs.html

(2) Annual Sequestration Potential in Protected Forests

The calculations in this section of the analysis used default carbon sequestration values for Oak-Hickory and Maple-Beech-Birch forest types in the Northeastern United States (USFS GTR-343, Tables A2 and A3). Average annual carbon sequestration for these forest types was calculated over 125 years by subtracting carbon stocks in 125-yr old stands from carbon stocks in new stands and dividing by 125 (Table LP1-4). Soil carbon density was assumed constant and is not included in the calculation because default values for soil carbon density are constant over time in USFS GTR-343.

Table LP1-4. Forest Carbon Sequestration Rates

	MtC/ac (0 yr)	MtC/ac (125 yr)	MtC/ac/yr (average)
Oak-Hic	23.0	110.7	0.7
Map-Bee-Bir	25.0	88.6	0.5

The results for annual sequestration potential under each of the three scenarios and four sets of assumptions are given in Table LP1-5. Since forests preserved in one year continue to sequester carbon in subsequent years, annual sequestration potential includes benefits from acres preserved cumulatively under the program. Carbon sequestration in protected acreage is calculated on the cumulative acreage protected, and thus does not vary with the assumptions about development threat.

Table LP1-5: Annual Sequestration Potential in Protected Forests

Year	Cumulative Acres Preserved			C Storage in Protected Acreage (MMtCO2e)		
	Scenario 1	Scenario 2	Scenario 3	Scenario 1	Scenario 2	Scenario 3
2008	20,000	20,000	20,000	0.044	0.044	0.044
2009	40,000	40,000	40,000	0.089	0.089	0.089
2010	60,000	60,000	60,000	0.133	0.133	0.133
2011	80,000	80,000	80,000	0.178	0.178	0.178
2012	80,000	100,000	120,000	0.178	0.222	0.266
2013	80,000	120,000	160,000	0.178	0.266	0.355
2014	80,000	140,000	200,000	0.178	0.311	0.444
2015	80,000	160,000	240,000	0.178	0.355	0.533
2016	80,000	180,000	280,000	0.178	0.399	0.621
2017	80,000	200,000	320,000	0.178	0.444	0.710
2018	80,000	220,000	360,000	0.178	0.488	0.799
2019	80,000	240,000	400,000	0.178	0.533	0.888
2020	80,000	260,000	440,000	0.178	0.577	0.976
Total	80000	260000	440000	2.04	4.04	6.04

Figures LP1-1 through LP-4 illustrate the projected total carbon savings, including both avoided emissions and sequestration potential through 2020, as a result of protecting PA forests under the three scenarios. Figure 1 shows carbon savings under the assumption of 100% threat of development (Assumption A). If 50% threat of development is assumed

(Assumption B), carbon savings are halved, to the levels illustrated in Figure LP1-2. Carbon savings decline further under the remaining Assumptions (C and D) about 20% and 10% development threat. Under all scenarios and assumptions, the majority of carbon savings result from avoiding emissions that would otherwise be generated by conversion.

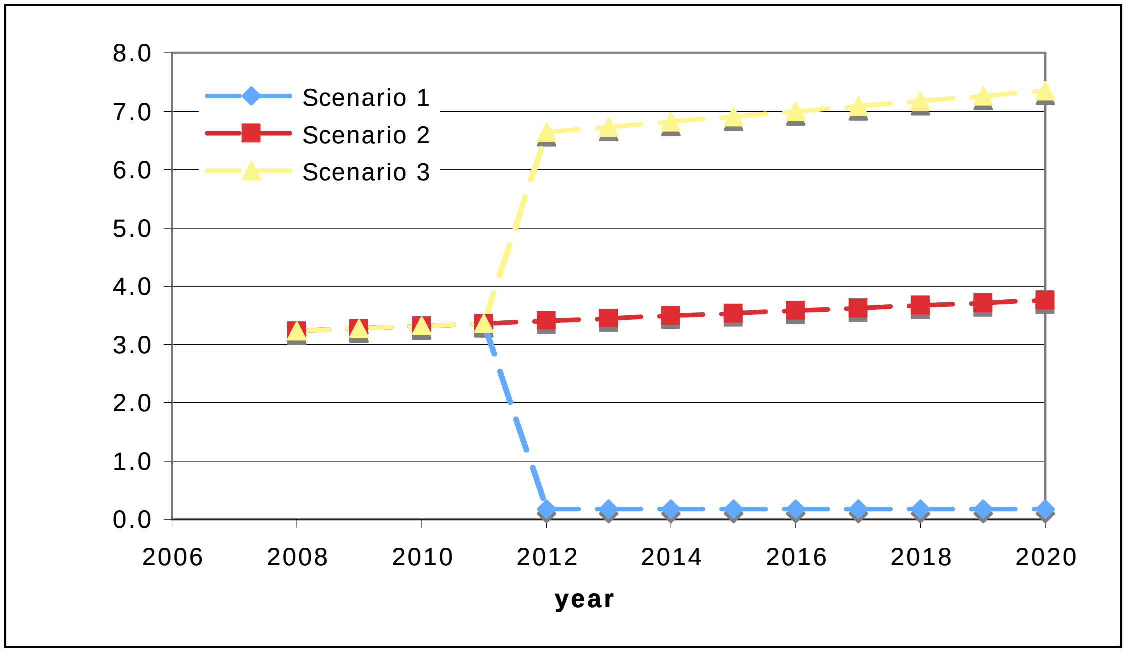


Figure LP-1. Carbon savings under Assumption A (100% development threat).

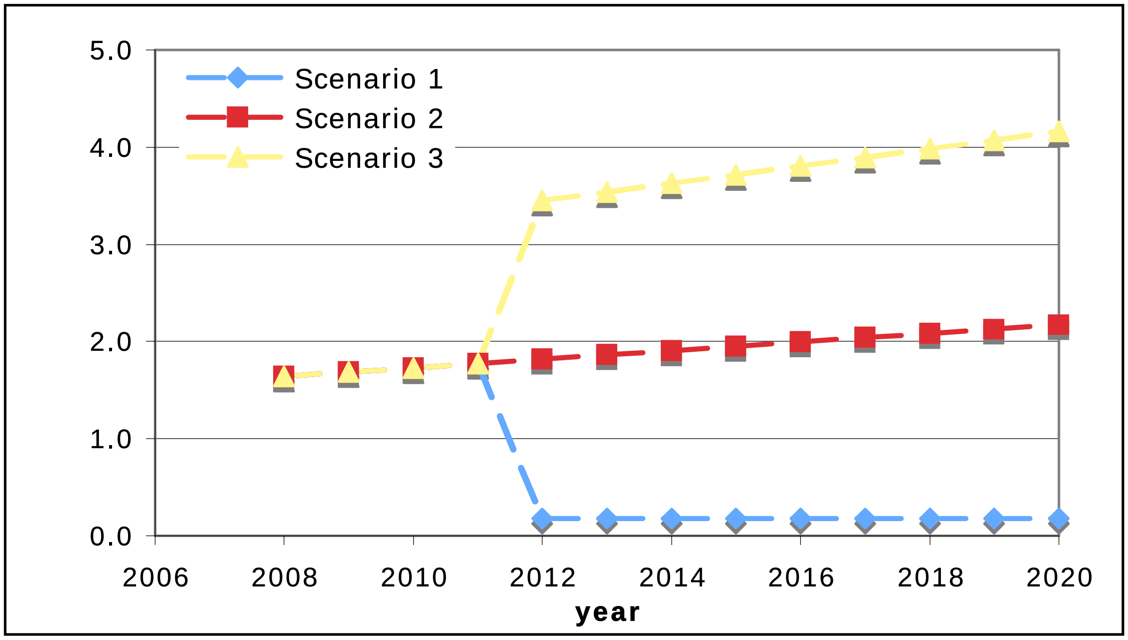


Figure LP1-2. Carbon savings under Assumption B (50% development threat).

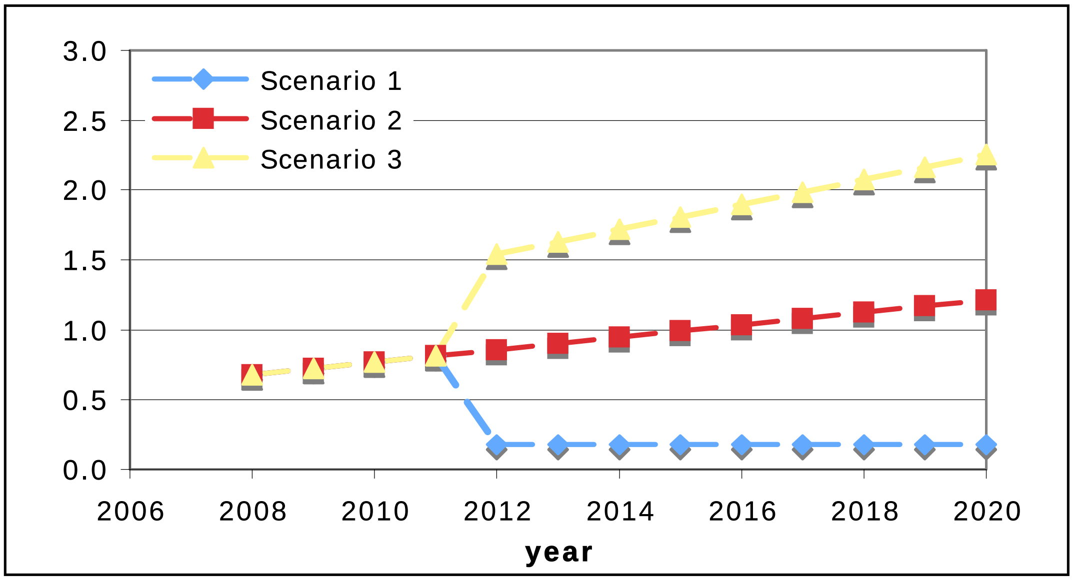


Figure LP1-3. Carbon savings under Assumption C (20% development threat).

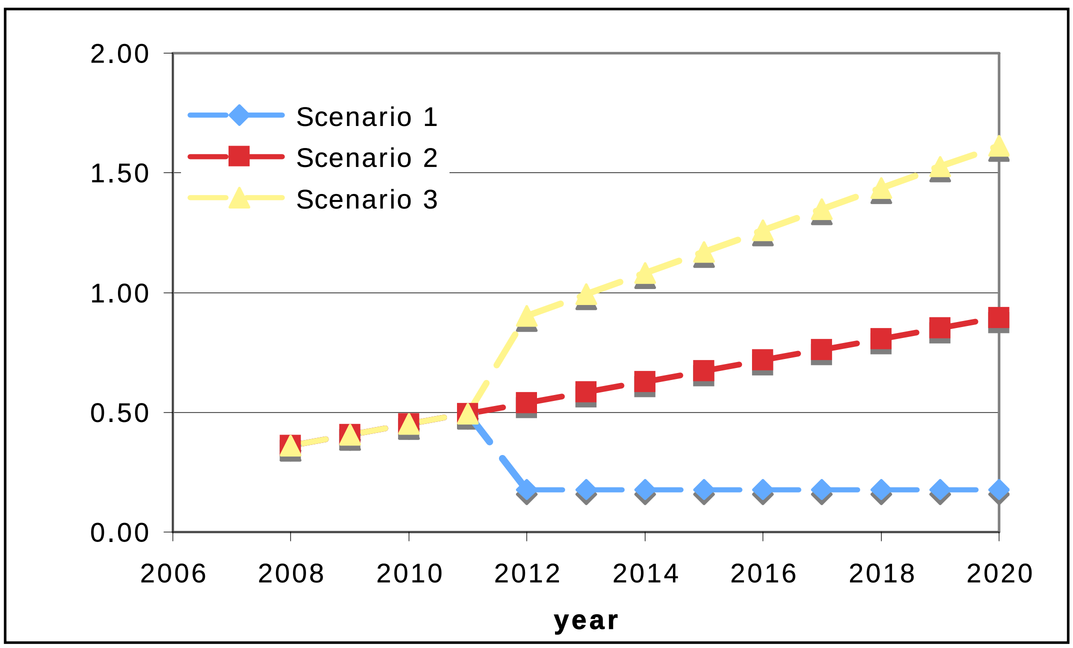


Figure LP1-4. Carbon savings under Assumption D (10% development threat).

(C) Economic Costs of Land Preservation

The economic cost of avoiding conversion was calculated as the cost of land acquisition. This is a one-time cost per acre of protected land and is estimated at $3,500 per acre**.** This is a statewide average based on DCNR experience; however, it should be noted that this figure is not necessarily representative of those lands at most risk to development, primarily in the southeast region of PA.

Costs were assumed to be one-time costs applied in the year that land is acquired. Maintenance costs are assumed to be zero. The analysis does not take into account potential cost savings, e.g., avoided land clearing costs and revenue from forest products on working forest lands that are protected under this policy. Discounted costs were estimated using a 5% interest rate. Total non-discounted and discounted costs under each Scenario are provided in Table LP1-6. The cumulative cost effectiveness of the total program was calculated by summing annual costs and dividing by cumulative carbon sequestration, yielding the results in Table LP1-7. Cost effectiveness varies by which set of assumptions is used relative to development threat. Figure LP1-3 compares cumulative carbon savings and cost effectiveness (calculated with discounted costs) for all scenarios.

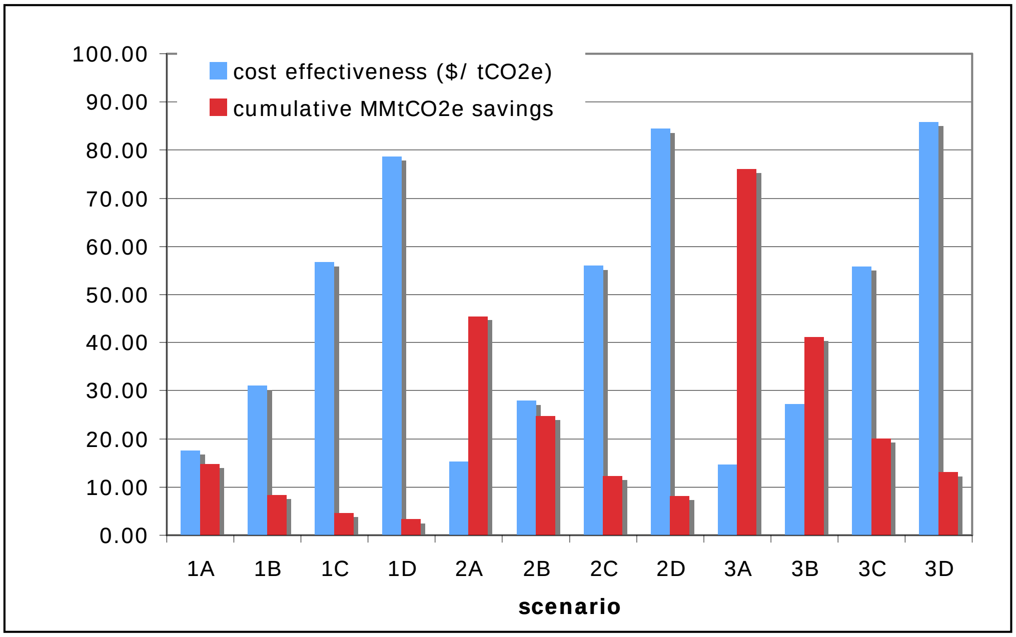
Table LP1-6: Costs and Discounted Costs for Alternative Scenarios

	Total Acres Acquired	Non-Discounted Costs	Discounted Costs
Scenario 1	80,000	$280,000,000	$260,627,362
Scenario 2	260,000	$910,000,000	$690,427,615
Scenario 3	440,000	$1,540,000,000	$1,120,227,867

Table LP1-7: Cost Effectiveness of Alternative Scenarios

Land acquisition scenario	Development threat	Cost effectiveness ($/ tCO2e)	Cumulative C savings (MMtCO2e)
1	100% (A)	$17.63	14.78
1	50% (B)	$30.98	8.41
1	20% (C)	$56.79	4.59
1	10% (D)	$78.61	3.32
2	100% (A)	$15.19	45.45
2	50% (B)	$27.91	24.74
2	20% (C)	$56.04	12.32
2	10% (D)	$84.41	8.18
3	100% (A)	$14.72	76.11
3	50% (B)	$27.27	41.07
3	20% (C)	$55.87	20.05
3	10% (D)	$85.89	13.04

Figure LP1-3. Comparison of Scenarios in terms of Cost Effectiveness and Total Carbon Savings



- **Key Assumptions:** Forest acquisition costs $3,500/ acre; 50% of protected forest will be in a Maple-Beech-Birch forest type and 50% of protected forest will be in an Oak-Hickory forest type. Conversion threat values may range from 10% to 100%.

Limitations

THE CMAG analysis is primarily intended to examine the roles of the State Forests and of DCNR as an agency in offsetting a portion of the Commonwealth's emissions. This should not be interpreted as minimizing the role of private forest landowners, who will have a vitally important role – and potentially important economic opportunities – under a carbon constraint regime. Programs or incentives for private forest landowners certification for sustainable management may be highly desirable.

Providing private landowners with technical assistance to guide forestland planning, encouraging responsible maintenance of private working forests through local ordinances, and providing tax incentives for forest conservation are all cost effective strategies for forestland conservation, in addition to traditional tools such as purchase of conservation easements and outright public acquisition.

This discussion of land conservation also does not assess the multiple benefits and utility of concentrating growth. Growth concentration/ sprawl reduction policy is beyond the scope of the CMAG inquiry.

2. Reduce Forest Conversion to Developed Use

Mitigation Option Description

This option seeks to reduce the rate of forest conversion, specifically targeting private forest land in order to reduce the rate of statewide forest conversion to developed uses.

Forests store significant amounts of carbon (C). Conversion of forests to other land uses releases that C to the atmosphere. Initiatives that protect forest land reduce C emissions to the atmosphere in two ways: a) avoided deforestation reduces the amount of C that would otherwise have been released to the atmosphere, and b) C sequestration in protected acreage sequesters additional carbon.

It is important to acknowledge that reducing forest conversion to zero is infeasible. That scenario is analyzed here for illustrative purposes only.

Mitigation Option Design

- **Scenarios:**
  - Scenario 1: Reduce the net rate of forest conversion by 25% by 2020.
  - Scenario 2: Reduce the net rate of forest conversion by 50% by 2020.
  - Scenario 3: Reduce the net rate of forest conversion to zero by 2020.
  - Scenario 4: Same as Scenario 2, but assume conversion threat of 20% (i.e. 5 acres are protected for each acre that is not developed)
  - Scenario 5: Same as Scenario 2, but assume conversion threat of 10% (i.e. 10 acres are protected for each acre that is not developed)
- **Timing:** In each scenario, the policy option is implemented linearly and gradually, with more acres protected each year. Full implementation is achieved by 2020 for all five scenarios.
- **Coverage of parties:** PA DCNR, land conservation organizations, private landowners

Potential Implementation Mechanisms

Private land mechanisms: technical assistance to guide local planning that would improve protection of forests (e.g., through extension service, or use of model ordinances); encourage local ordinances that do not prohibit or prevent maintenance of private working forests); provide greater tax incentives for private working forests.

Related Policies/Programs in Place

- State Clean and Green Program -- The Clean and Green as it is commonly known, is actually ACT 319. The Clean and Green program is a state program designed to preserve agricultural and forest land. The purpose of ACT 319 is to provide a real estate tax benefit to owners of agricultural or forest land by taxing that land on the basis of its "use value" rather that its market value. This act provides preferential assessment to any individuals who agree to maintain their land solely devoted to agricultural use, agricultural reserve, or forest reserve use. (http://www.agriculture.state.pa.us/agriculture/cwp/view.asp?a=3&q=129083).
- USFS Forest Legacy Program – Rural and Community Forestry Section (CFM) – identify forestland in highly developing areas and purchase conservation easements on property which keep the area in forest in perpetuity. http://www.na.fs.fed.us/legacy/index.shtm
- Bureau of Recreation, Community Conservation Partnerships Program (C2P2) grants for open space conservation

Types(s) of GHG Reductions

Avoided emissions from loss of carbon stocks and protection of annual carbon sequestration potential of forests.

Estimated GHG Savings and Costs per MTCO$_2$e

- **GHG reduction potential in 2010, 2020 (MMtCO$_2$e):** Varies by Scenario. See analysis, below.
- **Cumulative GHG reduction potential (MMtCO$_2$e, 2008-2010):** Varies by Scenario. See Analysis, below.
- **Net Cost per MtCO$_2$e:** See Analysis, below.
- **Data Sources:** US Forest Service Methods for Calculating Forest Ecosystem and Harvested Carbon with Standards Estimates for Forest Types of the US, General Technical Report NE-343 (also published as part of the Department of Energy Voluntary GHG Reporting Program). Data provided by the USFS for the PA Forestry Inventory and Forecast. Program costs provided by DCNR. Austin, K. 2007. The Intersection of Land Use History and Exurban Development: Implications for Carbon Storage in the Northeast. Undergraduate Thesis, Brown University.
- **Quantification Methods:**

GHG benefits from this option were estimated from two sources: (1) the amount of carbon that would be lost as a result of forest conversion to developed uses (i.e., "avoided emissions"); and (2) the amount of annual carbon sequestration potential that is maintained by protecting the forest area.

In PA, the Natural Resources Inventory (NRI) estimated roughly 15.5 million acres of forest in 1997. Between 1982 and 1997, 902,900 acres of forest were converted to nonforest use (61,393 acres annually). Of this total, 597,900 acres were converted to developed use for a net annual loss of 39,860 forested acres to development statewide.

This corresponds to a net forest loss of 0.40% year to all nonforest uses, or 0.26% loss annually to development alone. In this analysis, a baseline conversion rate of 39,860 acres per year was used, representing the rate at which forestland was lost to development annually between 1982 and 1997. Updated data on land conversion trends through 2002/2003 will be available in mid-2008, but had not been released in time for this report.

Analysis for each of these types of C savings (avoided emissions and sequestration on protected acreage) was conducted across five scenarios. The scenarios differ with regard to number of acres not converted to development each year, as well as the number of acres that must be purchased to avoid land conversion to developed use (i.e. conversion threat) (see Table LP2-1). In all scenarios, 50% of preserved forests are assumed to be Oak-Hickory and 50% are assumed to be Maple-Beech-Birch. These forest types were used because they are predominant in PA, each making up about 44% of total forest cover in PA (FIA).

Table LP2-1. Alternative Acreage Scenarios Used to Quantify Carbon Savings from Avoided Forest Conversion to Developed Use.

	Cumulative acreage protected 2008 – 2020 (acres)	Goal level, protected acreage by 2020 (ac/ yr)	Annual incremental acreage protected to reach goal (ac/ yr)	Cumulative acreage not developed 2008-2020 (acres)
Scenario 1: Reduce conversion rate by 25% by 2020	69,797	9,971	767	69,797
Scenario 2: Reduce conversion rate by 50% by 2020	139,503	19,929	1,533	139,503
Scenario 3: Achieve no net loss of forest to development by 2020	279,006	39,858	3,066	279,006
Scenario 4: Same as Scenario 2, but assume 20% conversion threat	139,503	19,929	1,533	27,901
Scenario 5: Same as Scenario 2, but assume 10% conversion threat	139,503	19,929	1,533	13,950

(1) Avoided Emissions

The forest carbon stocks (tons carbon per acre) and annual carbon flux (annual change in tons carbon per acre) data are based on default carbon sequestration values for Maple/Beech/Birch forest types in the Northeastern US (USFS GTR-343, Table A2). Annual rates of carbon sequestration (tons carbon sequestered per acre per year) were calculated by subtracting total carbon stocks in forest biomass of 125 yr old stands from total carbon stocks in forest biomass of new stands and dividing by 125. Soil carbon density was assumed constant and is not included in the annual carbon flux calculations because default values for soil carbon density are constant over time in USFS GTR-343. See Table LP1-2 in Option LP-1 above for overview of forest C storage and sequestration information used in this analysis.

Loss of forests to development results in a large one-time surge of carbon emissions. In this case, it was assumed that 100% of the vegetation carbon stocks would be lost in the event of forest conversion to developed uses, with no appreciable carbon sequestration in soils or biomass following development. The soil carbon loss assumption is based on a study that shows about a 35% loss of soil carbon when woodlots are converted to developed uses (Austin, 2007). A comparison of data from the American Housing Survey[2] with land use conversion data from the Natural Resources Inventory (NRI) suggests that, on average, two thirds of the land area in a given residential lot is cleared during land conversion. Thus, it was assumed that, during forest conversion to developed use, 100% of the forest vegetation C and 35% of the soil C would be lost on 67% of the converted acreage.

To estimate avoided emissions, the total number of acres protected in a year was multiplied by the estimate of one-time C loss from biomass and soils due to development. In Maple-Beech-Birch forests, this estimated C loss was 56.2 t C per acre; in Oak-Hickory forests, the estimated C loss was 49.2 t C per acre. In both forest types, this estimate of C loss due to development is calculated as the sum of 100% of average standing vegetation C stocks (live + dead) and 35% of average soil C stocks (forest floor + mineral soil). This overall avoided C emissions estimate was then converted to million metric tons of CO2 equivalents (MMTCO2e) for inclusion in Table LP2-2 (below). While some of the biomass lost during clearing might be used for bioenergy production, this effect was not quantified in the analysis of LP-2.

For Scenarios 1-3, it was assumed that 100% of the protected land would otherwise have been converted to a developed use. Thus for these Scenarios the avoided emissions calculation was made on 100% of the protected acreage. Scenarios 4 and 5 assume that only 20% and 10%, respectively, of the land that is protected would otherwise have been developed. Calculations using these Scenarios assume that the protected acreage is the same as under Scenario 2, but that avoided emissions due to land conversion occur on only a fraction of the acreage that is actually protected.

(2) Sequestration in Protected Forest

Forests not converted in a given year continue to sequester carbon each year they remain in a forested use. Thus the C sequestration in protected forestland is calculated as annual sequestration in cumulative protected acreage. Annual sequestration for PA forest (t C / ac/ yr) is calculated from NE-GTR-343 and is given in Table LP1-4 in Option LP-1 (above). As with avoided emissions from initial conversion, it is assumed that half of the protected forests are in Maple-Beech-Birch forest and half are in Oak-Hickory forest. Because acres protected in one year continue to store C in subsequent years, annual benefits of forest protection tend to accrue in later years of policy implementation (Figure LP2-1).

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[2] US Census, http://www.census.gov/hhes/www/housing/ahs/ahs.html

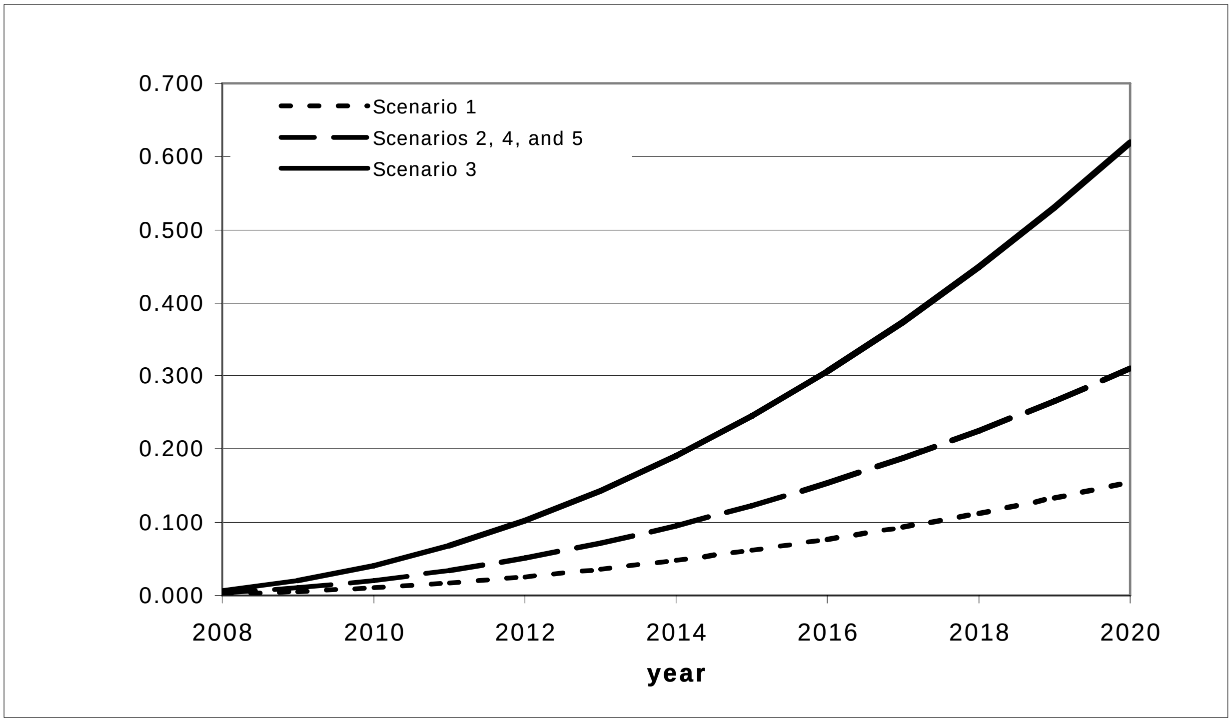


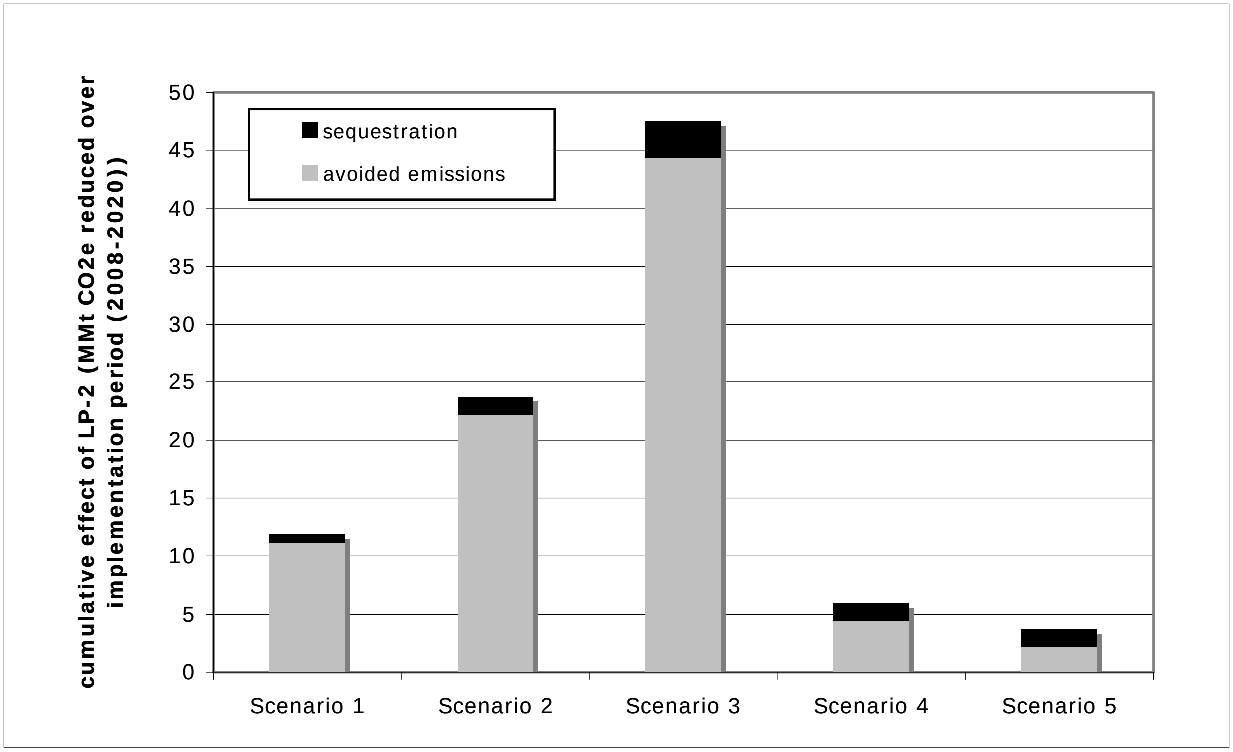
Figure LP2-1. Impact of Forest Protection from Conversion on Annual C Sequestration in Cumulative Protected Acreage.

For Scenarios 1-3, the relative impact of avoided one-time emissions due to reduced forest conversion is roughly fourteen times the impact of cumulative sequestration in protected acreage for all Scenarios (Table LP2-2, Figure LP2-2). For Scenarios 4 and 5, the relative impact of avoided emissions from development is much smaller, consistent with the assumption that avoided emissions are effective on only a fraction of the forest land.

Table LP2-2. Summary of Avoided One-Time Emissions and Sequestration in Protected Forest due to Reduced Forest Conversion (2008-2020).

	Cumulative acres protected (2008-2020) (acres)	Cumulative GHG benefit from avoided one-time emissions (2008-2020) (MMt CO2e)	Cumulative GHG benefit from C sequestration in protected forest (2008-2020) (MMt CO2e)
Scenario 1	69,797	11.1	0.8
Scenario 2	139,503	22.2	1.5
Scenario 3	279,006	44.4	3.1
Scenario 4	139,503	4.4	1.5
Scenario 5	139,503	2.2	1.5

Figure LP2-2. Cumulative effect of five Scenarios on GHG emissions between 2008 and 2020.



(3) Economic Analysis

The economic cost of avoiding conversion was calculated as the cost of acquiring conservation easements on private land. This is a one-time cost per acre of protected land and is estimated at $3,500 per acre. Half of this easement cost ($1,750) is typically paid by the State, with a 100% match from private funds.[3]

Results of the economic analysis, without discounting, are shown in Table LP2-3. Since Scenarios 4 and 5 assume the same number of acres is purchased as in Scenario 2, the economic costs for Scenarios 2, 4, and 5 are equivalent.

[3] CMAG and Paul Roth, personal communication with J. Jenkins, December 2007 and January 2008.

Table LP2-3. Net Economic Costs of Avoided Forest Conversion (not discounted).

	Scenario 1	Scenarios 2, 4, and 5	Scenario 3
2008	$2,684,500	$5,365,500	$10,731,000
2009	$5,369,000	$10,731,000	$21,462,000
2010	$8,053,500	$16,096,500	$32,193,000
2011	$10,738,000	$21,462,000	$42,924,000
2012	$13,422,500	$26,827,500	$53,655,000
2013	$16,107,000	$32,193,000	$64,386,000
2014	$18,791,500	$37,558,500	$75,117,000
2015	$21,476,000	$42,924,000	$85,848,000
2016	$24,160,500	$48,289,500	$96,579,000
2017	$26,845,000	$53,655,000	$107,310,000
2018	$29,529,500	$59,020,500	$118,041,000
2019	$32,214,000	$64,386,000	$128,772,000
2020	$34,898,500	$69,751,500	$139,503,000
cumulative	$244,289,500	$488,260,500	$976,521,000

A summary of the discounted and non-discounted costs is shown in Table LP2-4, and overall results of the analysis are given in Table LP2-5. Discounted costs were calculated assuming a 5% discount rate. The net present value (NPV) of each Scenario is the sum of the discounted costs between 2008 and 2020. Levelized cost effectiveness is calculated as the cost associated with avoiding or storing each tCO2e. The levelized cost effectiveness of this option is the same for Scenarios 1-3, at $14.08/ tCO2e. The levelized cost per tCO2e reduced for Scenarios 4 and 5 is substantially larger, at $55.84/ tCO2e and $88.75/ tCO2e, respectively.

Table LP2-4. Summary of economic costs of 5 Scenarios of forest preservation under LP-2.

	Scenario 1	Scenarios 2, 4, and 5	Scenario 3
Total economic costs (non-discounted) ($ million)	$244.3	$488.3	$976.5
Total economic costs (NPV) (discounted) ($ million)	$167.4	$334.5	$669.1

Table LP2-5. Summary of GHG benefits and Economic Costs for 3 Scenarios Quantified Under Option LP-2.

	GHG reduction potential in 2010 (MMtCO2e)	GHG reduction potential in 2020 (MMtCO2e)	Cumulative GHG reduction potential 2008-2020 (MMtCO2e)	Cost effectiveness ($ per t CO2e)
Scenario 1: Reduce rate of conversion by 25% by 2020	0.4	1.7	11.9	$14.08
Scenario 2: Reduce rate of conversion by 50% by 2020	0.8	3.5	23.8	$14.08
Scenario 3: Achieve no net forest loss by 2020	1.5	7.0	47.5	$14.08
Scenario 4: Same as Scenario 2, but assume 20% conversion threat	0.2	0.9	6.0	$55.84
Scenario 5: Same as Scenario 2, but assume 10% conversion threat	0.1	0.6	3.8	$88.75

Key Assumptions: Forest protection will occur via easements, which cost $3,500/ acre; 50% of protected forest will be in a Maple-Beech-Birch forest type and 50% of protected forest will be in an Oak-Hickory forest type. Conversion threat values may range from 10% to 100%.

Limitations

A comprehensive statewide analysis of acres protected vs. acres developed to date in PA is beyond the scope of the CMAG inquiry.

State land use policy is beyond the scope of the CMAG process; however, given its potential climate implications, interagency cooperation and collaboration to consider policies to limit sprawl such as smart growth, location efficient development, and minimizing vehicle miles traveled as part of a comprehensive carbon strategy are highly desirable.