Title: Potential Carbon Sequestration and Revenue from Timber and Carbon Credits for Landowners of West Virginia Abandoned Mine Lands.

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Manuscript Abstract (50 words or less):
An optimal forest rotation model estimates potential value from timber and carbon for owners of WV abandoned mine lands (AMLs). An OLS regression provides merchantable volume and carbon density for six forest types which could sequester 0.41 Tg of carbon per year on approximately 33,800 hectares of AMLs.

Keywords: Carbon sequestration, abandoned mine lands, reforestation, Faustmann model

I. Introduction

Although the U.S. has not signed the Kyoto Protocol, greenhouse gas (GHG) emission caps and emission trading schemes remain relevant to U.S. industries and governments. For example, the Chicago Climate Exchange (CCX), a pilot GHG emission trading program, has members from several U.S. companies such as Ford, DuPont, and American Electric Power Company who have agreed to voluntary track, trade, and reduce GHG emissions (CCX "Members" 2005). Though the federal government might be moving slowly towards possible GHG regulations, New York, Delaware, New Jersey, Connecticut, Maine, Massachusetts, New Hampshire, Rhode Island, and Vermont have already begun establishing a GHG emissions cap for power plants in the northeastern U.S. (Reuters 2005).

As GHG emissions become important to U.S. businesses and governments, carbon sequestration activities such as reforestation develop a value. In order to count for carbon sequestration credits, reforestation activities must be the re-establishment of forests on land that has been deforested for an extended period of time but with a history of forest cover as narrowly defined by the Intergovernmental Panel on Climate Change (IPCC 2000). The nearly 400,000 acres of abandoned mine lands (AMLs) in the U.S. meet this definition and present an opportunity for landowner income with minimal costs.

In order to gain jobs and tax revenue, communities and landowners accepted the safety and environmental costs of AMLs. In 1977, the coal mining industry became accountable for the costs of AMLs with the passage of Title IV of the Surface Mining Control and Reclamation Act (SMCRA) which implementing a \$0.35 per ton tax on surface mined coal, a \$0.15 per ton tax on underground mined coal, and a \$0.10 per ton tax on lignite (1977). The cost of Title IV of SMCRA is spread over the millions of electric utilities customers who account for approximately 90% of the coal market and AML landowners could utilize the AML funds to establish forests and generate revenue from timber and carbon credits (Flynn, 2002). Along with helping landowners in West Virginia, reforestation of AMLs could help utilities in states such as Colorado, New Mexico, North Dakota, Wyoming, and Utah who produce over 80% of their electricity from coal by reducing the cost of meeting any future carbon emissions standards (DOE 2004). Therefore, this paper analyzes West Virginia, which contains the largest area of AMLs, to determine the potential carbon sequestration, and the possible revenue from timber and carbon credits.

II. LITERATURE REVIEW

While many global climate change economic studies have focused on reduction of greenhouse gas emissions, several have analyzed the potential and cost for carbon sequestration in forests. Since forests were estimated to reduce the overall cost of stabilizing U.S. carbon emissions by 80%, Sedjo et al. (1995) gauged the assumptions, results, and weaknesses of existing studies on mitigating atmospheric carbon and discussed need future research. In their examination, Sedjo et al (1995) noticed an improvement in the each generation of research in the areas of estimating cost functions and developing in models to examine the implication of forest management policies. The weakness of these forest policy models according to Sedjo et al (1995) is a lack of including the reaction of the private sector which currently plants 80% of trees to increased government plantings. Since afforestation, reforestation, and deforestation are types of land use change, Lubowski, Plantinga, and Stavins (2005) modeled six types of land used for the U.S. using econometric data on landowner preferences. Using land use transitions recorded by the National Resource Inventory (NRI) between 1982 and 1997, Lubowski, Plantiga, and Stavins (2005) developed a carbon sequestration supply curve that was compared to engineering costs studies and sector optimizing models. Lubowski, Plantiga, and Stavins (2005) showed an almost doubling of forest area from 405 to 754 million acres by the model when a $100 per acre tax/subsidy was implemented. In comparison to other studies, Lubowski, Plantiga, and Stavins' (1995) model demonstrated higher marginal costs, but indicated that forest-based sequestration along with carbon abatement strategies could cost effectively achieve a third of the U.S. Kyoto Protocol target. Review of forest sequestration literature provided information on cost per ton of carbon that can be compared to cost of sequestering carbon on AMLs.

Determining carbon sequestration potential of abandoned mine lands requires reviewing literature on the biological productivity on reclaimed mines as well as the on the economic potential to sequester carbon in soils and above-ground biomass on AMLs. To determine the health and value of timber on lands mined before SMCRA, Rodrigue, Burger, and Oderwald (2002) compared 14 mined sites to 8 nonmined sites in Indiana, Illinois, Kentucky, Ohio, West Virginia, Pennsylvania, and Virginia. Tallying trees greater than 13 cm in diameter at breast height allowed Rodrigue, Burger, and Oderwald (2002) to state that pre-SMCRA mined sites may develop into healthy, productive, and diverse forests with a productivity ranging between 38% lower to 200% greater than nonmined sites. Since mine sites have been shown as able to support growth, several studies have examined the carbon sequestration potential as well as timber value potential. Huang et al (2004) employed Forest Management Optimizer (FORMOP) software to simulate growth, thinning, and harvesting of a stand of northern red oaks planted on various AML sites in West Virginia. Though Huang et al (2004) found a negative return for managing timber and carbon with different rates of return, they counter by saying that a partnership of electric utility companies and AML landowners could have other environmental benefits such as improved aesthetics and greater wildlife habitat. Current models regarding carbon sequestration on mine lands utilizes broad generalizations about the area of unreclaimed mine land, the carbon sequestration rates of soils, and type of vegetation planted on the mine sites to develop payment estimates, but hopefully, ongoing research by Department of Energy will be able to address these deficiencies.

III. METHOD AND DATA

A. Data

Analysis of the potential of AMLs to grow timber and sequester carbon requires data on the area available, the cost of reclamation and planting trees on AMLs, the prices available for timber and carbon credits, and the rates of growth and carbon sequestration for various tree species.

Area: In order to determine the area of land available for sequestration activities, this study utilized the Office of Surface Mining's (OSM) Abandoned Mine Land Inventory System (AMLIS). Entries in the AMLIS database contain information for various problems at an AML site. The information includes a FIPs code for location, a problem description code, a value for the acreage in Government Performance and Results Act (GPRA) units, percentage of ownership, and a cost to fix the problem. The SMCRA Title IV Section 403 (a) designates all AMLs with a one to five priority code, but only reporting of Priority 1 and 2 is required because these problems pose a threat to the health, safety, and general welfare of people. Examples of Priority 1 and Priority 2 problems are dangerous slides (DS), portals (P), and underground mine fires (UMF). Only a few states report the non-threatening environmental problems, so not all Priority 3 sites are listed in the AMLIS. Examples of Priority 3 problems are benches (BE) and slurries (SL). Since some AML problems are not measured in acres such as the feet of a highwall or the number of portal openings, OSM converts all units into GPRA acres in order to measure cost effectiveness (OSM 2004 December). This analysis summed the GPRA acres by FIPs codes to calculate the AML area by county which would be the basis for calculating timber and revenue amounts by county.

Analysis of the best opportunities for afforestation or reforestation on AMLs requires filtering of AMLIS entries. Not all AML problems, such as underground mine fires and water problems, present opportunities to grow vegetation; therefore the GPRA acres for these problems were removed for this study. In the AMLIS system, an abandoned mine problem is specified as either an unfunded project, a funded but not complete project, or a completed project. Completed projects were used to estimate average reclamation costs per county, but these projected were removed when determining the potential area for tree growth. The hectares within each state of abandoned mine lands that are available for carbon sequestration are calculated by adding the Unfunded and Funded columns within Table 1. As seen in Table 1, West Virginia has the largest unfunded AML area with over 33,800 hectares.

Reclamation Costs: Reclamation costs vary greatly between AML sites depending on type of problem, climate, topography, and other factors. Using costs for completed AML projects provides a picture of the range of costs for various types of problems. Climate and topography impact reclamation costs by limiting the type of equipment feasible and influencing the number of hours for completion.

Since reclamation costs differ by site, this analysis presents two scenarios landowners could face. The first scenario assumes that the current AML tax system is extended for a 25 year period as suggested by environmental groups such as The Citizen Coal Council (CCC 2005). An extension of the tax implies that the AML fund could cover all reclamation expenses, so the landowner would have $0 in costs. To satisfy western coal producers, Representative Barbara

Cubin (WY) sponsored bill H.R. 1600 which lowers the AML tax levels to $0.28 per ton on surface mined coal, $0.12 per ton on underground mined coal, and $0.08 per ton on lignite (US HR 2005); therefore the second scenario assumes a landowner must cover a portion of overall costs. By assuming that the AML Fund pays to return the ground to a state able to grow vegetation, then the landowner would cover the cost of planting trees. Planting trees by hand is recommend on AMLs in West Virginia due to steep terrain, so the average cost comes from buying trees from nearby nurseries plus the $0.08/ tree for labor (Dubois et al 2003). Using 7' x 7' spacing for hardwoods and 8' x 8' for pines provides the number of trees per hectare, shown in Table 2, which is multiplied by the average cost to calculate total cost per hectare for landowners (Ashby and Vogel 1993).

Timber and Carbon Prices: Estimating the potential revenue for an AML requires prices for timber and carbon sequestration. From 1987 to 1997, the largest forest types in the northeast were Maple (*Acer*), Beech (*Fagus*), and Birch (*Betula)* with an average of 12,727 ha; Oak (*Quercus*) and Hickory (*Carya*) with an average of 10,175 ha; Spruce (*Picea*) and fir (*Abies*) with an average of 3,875 ha; White (*Pinus strobes*), Red (*Pinus resinosa*), and Jack pine (*Pinus banksiana*) with an average of 2,911 ha; Aspen (*Populus tremula*) and Birch with an average of 1,481 ha; Elm (*Ulmus*), Ash (*Fraxinus*), and Cottonwood (*Populus deltoides*) with an average of 1,289 ha (Birdsey 2003). Therefore, these species were selected for the analysis of West Virginia. The real price of timber for each tree species, shown in Table 5, was calculated using the volume and value of sawtimber stumpages for the eastern region from National Forests (Howard 1997). Rather than holding the carbon credit constant, the sensitivity of the model was analyzed by varying carbon credits prices between $0, $50, and $90.75. A carbon price at $0 provides a model for the optimization of timber alone. To evaluate the impact of a carbon credit on the optimal rotation age, the carbon price was set at $50 per metric ton because it is a price utilized in carbon sequestration studies by Hoen and Solberg (1997) and Hoen (1994). On December 2, 2005, the EU ETS market showed a price of $24.75 per metric ton of carbon dioxide which is converted to $90.75 per metric ton of carbon (Chicago Climate Exchange 2005).

Timber Yield, Carbon Sequestration, and Emissions Equations: Equations to calculate the volume of merchantable timber and the amount of carbon sequestered by growing stand were estimated from data in Table A1 to A6 in Appendix 1 of the *Technical Guidelines for the Revised 1605(b) Voluntary Greenhouse Gas Reporting* (DOE). An OLS regression of this data using Excel provided the equations for volume of merchantable wood and the carbon density of various tree species as function of time. For example, a regression analysis of the data for merchantable volume for the Aspen and Birch tree species had the results shown in Table 3. The mean merchantable timber volume (m^3/ ha) had the following quadratic form:

(1) $Q(t) = 0.0083t^2 + 1.880379t - 15.622$.

Though an AML landowner would receive credit for storing carbon in the trees, it is assumed that the landowner would also be responsible for the emissions caused by the harvest of the forest. Since carbon pools in wood products such as furniture and lumber, not all carbon is counted as emissions into the atmosphere at the time of harvest. After harvest, carbon emissions occur over 100 years until approximately 12.5% of the original carbon density remains (DOE 2005). Using Hardwood Pulpwood in the Northeast data found in Table 3 in Section 4 of Appendix 1 in *The Technical Guidelines for Voluntary Greenhouse Gas Reporting*, this project developed an equation for the percentage of emissions of carbon (DOE 2005).

B. Model

Optimization models for the timber rotation have been employed since Faustman in 1849. Assuming that a timber company will maximize profits, Faustman realized that the value of the land is an infinite number of rotations of trees and developed the Bare Land Value (BLV) equation. The BLV model is appropriate for AMLs because it provides the value of land that is changed from no vegetation to forest land cover. Since the Faustmann model only accounted for timber revenue, Hoen (1994) and Murray (2000) modified it to include carbon value as a benefit. The Bare Land Value of Timber and Carbon (BLV_{TC}) model calculates the present value of the profits from infinite rotations and is shown in equation (2):

$$(2)\ BLV_{TCi} = [p_i * Q(T)_i * e^{-rT} - R_i + \int_0^T v * C'(t)_i * e^{-rt} dt - [vC(T)_i \int_0^D d(s) * e^{-rs} ds] * e^{-rT}] * [1 - e^{-rT}]^{-1}$$

Variables:

BLV_{TC} = bare land value of a timber and C forest management regime. The bare land value refers going from zero vegetation to forest land use.
i = tree species
p_i = price of timber for tree species i
Q(T) = timber volume at the time of harvest for tree species i
e^{-rT} = method to discount timber revenue
T = rotation age
R_i = cost of forest establishment for tree species i
v = price of carbon unit
$C'(T)$ = marginal amount of carbon sequestered for tree species i
r = real discount rate (5%)
$C(T)$ = Total amount of carbon sequestered at the end of the rotation age for tree species i
d(s) = amount of C released s years after harvest on site or from wood products
D = length of time after harvest that C releases occur
e^{-rs} = method to discount emissions to time of harvest

If the value of carbon credit is set at $0 (i.e. v = 0), then the BLV becomes the same model as developed by Faustmann in 1849.

To determine the optimal rotation age for a stand of tress requires maximizing the BLV. The derivative of the BLV with respect to time provides equation (3):

$$(3) \quad p_i * Q'(T)_i + v * C'(T)_i[1 - \int_0^D d(s) * e^{-rs} ds] + r[v * C(T)_i * \int_0^D d(s) * e^{-rs} ds] = r * [p_i * Q(T)_i] + [r * BLV_{TCi}]$$

The left side of equation (3) is the marginal benefit and it consist of the marginal revenue of extending the rotation another period or of rotation delay which consists of the additional value from timber growth, the net value of additional C credits, and interest on the forestalled payments of C debits from harvest (Murray 2000). The right side of equation (3) presents the marginal cost of extending the rotation another period or the opportunity cost of rotation delay (Murray 2000). The costs consist of the interest on value of the timber and the interest on present value of an infinite series of rotations.

IV. RESULTS AND DISCUSSION

A. Results

Potential Carbon Sequestration: By assuming that all abandoned mine land is planted with the same species of trees, the maximum potential carbon sequestration for West Virginia may be calculated from the OLS carbon density equations. As shown in Table 4, the aspen and birch trees present the best opportunity to sequester 8.2 Tg of carbon over 20 on the 34,374 ha of AMLs. To make a comparison, the Mountaineer Power Plant in WV supplies 8.6 million MW-hr of electricity per year and emits 2.05 Tg of carbon a year (U.S. Senator Patrick Leahy 2005). Therefore, planting Aspen and Birch trees on AMLs could recover 20% of these emissions.

Revenue from timber and carbon credits: Though Aspen and Birch sequester the most carbon, the Oak and Hickory forest types generate the most merchantable volume of timber. As shown in Table 5, the Oak and Hickory forest types also have the highest timber price, so Oak and Hickory could generate approximately $8,447/ ha in timber after 20 years. On the other hand, using the carbon density for Aspen and Birch along with the current EU Emissions Trading Scheme price of $90.75/ metric ton C demonstrates that Aspen and Birch forest types can generate approximately $21,835/ ha in carbon credits. The last column of Table 5 shows that over a 20 year time span, each forest type generates nearly the same amount of revenue, but Aspen and Birch forest would earn the most revenue.

B. Sensitivity Analysis

Impact of Cost on Profits: Adding costs into the BLV model greatly affects, the viability of growing trees on AMLs. As shown in Figure 1, assuming a simple cost of $872/ ha which is the equivalent of planting 890 Aspen and Birch trees per hectare multiplied by an average cost of $0.98 per tree drops the profit or BLV equation into a negative range over the entire time period.

V. CONCLUSION

Planting West Virginia AMLs with trees could potentially sequester .24 Tg of carbon/ year to 0.41 Tg of carbon/ year. In contrast, West Virginia from 1990 to 2001 had average carbon emissions of 26.5 Tg of Carbon per year from fossil fuel consumption (EPA 2001). Though planting trees on WV AMLs could only account for 1.5% of WV carbon emissions, the trees could provide much needed revenue to landowners within the state. Along with providing revenue, afforestation and reforestation would provide other values such as better aesthetics, improved water quality from a reduction in run off, and a greater amount of wildlife habitat. If the AML tax is continued, landowners in West Virginia, Pennsylvania, Ohio, Kentucky and Virginia, which contain 65% of total AML area, could greatly benefit while providing opportunities for coal power plants in the western U.S. to offset emissions with carbon credits. This analysis shows that trees planted on AMLs have great potential to add revenue for landowners in the West Virginia, but it will depend on the costs and support of the government.

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TABLES

Table 1: Area of Abandoned Mine Lands in Hectares for All States

State	Unfunded (Hectares)	Funded (Hectares)	Completed (Hectares)	State	Unfunded (Hectares)	Funded (Hectares)	Completed (Hectares)
AK	113	0	164	**NC**	0	0	0
AL	28,915	264	9,399	**ND**	651	0	603
AR	1,260	387	1,678	**NM**	243	56	194
AZ	0	0	0	**OH**	15,576	135	4,045
CA	1	0	1	**OK**	10,326	121	1,592
CO	495	19	807	**OR**	3	0	0
GA	15	2	80	**PA**	14,056	2,493	8,043
IA	2,104	29	1,292	**RI**	0	0	0
ID	0	0	0	**SD**	1	0	1
IL	1,277	203	3,552	**TN**	3,711	340	1,174
IN	906	170	3,166	**TX**	502	58	1,065
KS	5,827	27	1,155	**UT**	87	0	358
KY	8,639	1,103	6,372	**VA**	14,325	60	1,019
MA	0	0	0	**WA**	103	0	8
MD	586	3	708	**WV**	33,772	185	6,221
MI	14	0	31	**WY**	1,518	51	11,478
MO	4,648	39	2,115	**TOTAL**	**154,905**	**6,112**	**72,044**
MT	474	11	1,327				

Table 2 : Total Tree Planting Cost Broken Down Into the Recommended Planting Rates, Tree Prices, and Labor Cost

Tree Species	Planting (Trees/ ha)	Price ($ / Seedling)	Source	Labor ($/ Seedling)	Total Cost ($/ ha)
Aspen and Birch	890	0.9	Carino 2005	$0.08	$872.20
Elm, Ash, and Red Maple	890	0.52	Ohio 2005	$0.08	$534.00
Maple, Beech, and Birch	890	0.4	Ohio 2005	$0.08	$427.20
Oak and Hickory	890	0.6	Ohio 2005	$0.08	$605.20
Spruce and Balsam Fir	680	0.2	WV 2005	$0.08	$190.40
White, Red, and Jack Pine	680	0.2	WV 2005	$0.08	$190.40

Table 3: OLS Regression Results for Merchantable Timber Volume of the Aspen and Birch Forest Type

	Coefficients	*Standard Error*	*t Stat*	*P-value*
Intercept	-15.33702593	1.412507579	-10.858	1.67E-08
X Variable 1	1.880379257	0.036305654	51.79301	2.49E-18
X Variable 2	0.008282379	0.000195369	42.39358	4.92E-17

Table 4: Potential Carbon Sequestration and Revenue ($97.50/ metric ton C) for 34, 374 ha of WV AMLs Planted with Various Tree Species

	Carbon Density (tons C/ ha) @ 20 yrs	Carbon Density (tons C/ ha) @ 175 yrs	20 Year Carbon (Tg/ Yr)	Max 175 Year Carbon (Tg)	Carbon Revenue ($/ ha/ yr) @ 20 yrs	Carbon Revenue ($/ ha) @ 20 yrs	Carbon Revenue ($/ ha / yr) @ 175 yrs
Aspen & Birch	241	522	0.41	17.94	1,092	21,835	271
Maple, Beech & Birch	182	323	0.31	11.11	826	16,530	168
Elm, Ash, & Red Maple	181	382	0.31	13.12	819	16,384	198
Oak & Hickory	142	519	0.24	17.84	644	12,887	269
Spruce & Balsam Fir	214	326	0.37	11.22	970	19,409	169
White, Red, & Jack Pine	214	288	0.37	9.89	973	19,451	149

Table 5: Timber Revenue Potential for 34, 374 ha of WV AMLs Planted with Various Tree Species

	Timber (m3/ ha) @ 20 yrs	Timber (m3/ ha) @ 175 yrs	Timber Price ($ / m^3)	Timber Revenue ($/ ha) @ 20 yrs	Timber Revenue ($/ ha) @ 175 yrs	Total Revenue ($/ ha) @ 20 yrs
Aspen & Birch	25	568	55	1,395	31,290	23,230
Maple, Beech & Birch	45	323	78	3,535	25,134	20,064
Elm, Ash, & Red Maple	49	382	83	4,066	31,549	20,449
Oak & Hickory	72	519	117	8,447	60,733	21,334
Spruce & Balsam Fir	24	326	43	1,034	14,075	20,443
White, Red, & Jack Pine	42	288	59	2,450	16,936	21,901

FIGURES

Figure 1: Net Present Value of Profit from the Timber for Aspen and Birch Trees Planted on AMLs with $0/ ha Cost and $872.20/ ha