Reforestation

Initiative Summary:
This initiative focuses on enhancing carbon storage in existing forests that have been poorly managed. Reforestation efforts aimed at re-stocking/planting and restoration practices (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 also eligible to generate offset credits.

Goal:
Restock under-stocked land via one of three scenarios:
- 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.

Implementation Period: 2013–2020

Methodology:
Forests that are not fully stocked do not grow as quickly as fully stocked stands. This analysis quantifies the costs and benefits of restocking under-stocked timberland acreage in PA (timberland is defined by USFS as land that is capable of producing ≥20 cubic feet/acre/year of industrial wood). The total acreage in PA timberland, by stocking class, is displayed in Table 1 and is sourced from USFS FIA, 2004. The scenarios developed for this initiative are shown in Table 2.

Table 1. Acreage of Timberland by Stocking Class in PA

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

Table 2. Scenario Acreages for Poorly and Moderately Under-Stocked Forestland

Scenarios	Annual Acreage to be Restocked		Total	Proportion of Under Stocked land restocked through 2020
	Poorly Stocked	Moderately Stocked		
Scenario 1: 100% of poorly stocked land	164,975	0	164,975	19.2%
Scenario 2: 100% of poorly and 50% of moderately stocked land	164,975	347,813	512,788	59.6%
Scenario 3: 100% of poorly and moderately stocked land	164,975	695,625	860,600	100%

Since the most feasible approach for restocking involves harvesting under-stocked 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 carbon 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 carbon 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 such as is quantified in the Fuels for Schools work plan initiative.

The total live tree carbon in under-stocked forests 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 GTR- NE-343, as noted in Table 3. 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 carbon and soil carbon due to harvest.

Table 3. Live Tree Biomass in Under-stocked Stands in PA

Forest Types	Poorly Stocked Volume (ft^3/acre)	Live Tree Carbon Stock (tC/acre)	Notes	Moderately Stocked Volume (ft^3/acre)	Live Tree Carbon Stock (tC/acre)	Notes
Maple-Beech-Birch	845.61	21.5	Table A2, corresponds to 25 years old, 830 ft^3/acre	1,657.04	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	1,411.52	29.1	Table A3, corresponds to 25 years old, 1,368 ft^3/acre
Average		**19.45**			**32.3**	

ft^3 = cubic feet; tC = metric tons of carbon.
Source: J.E. Smith et al., 2006.

The Durable Wood Products work plan details methodology used to quantify the carbon 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 (durable wood products (DWP's) 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 carbon eventually stored in long-term pools. This number was then subtracted from the total carbon in the under-stocked forest for acres cleared each year to estimate the net GHG impact of harvest shown in Table 4.

Table 4. Annual Carbon Emissions Due to Harvest for Restocking

Scenarios	Acres Harvested Annually		Vegetation Carbon Stock Emitted (MMtC/year)	Carbon Stored in DWPs (MMtC/year)	~~Net~~ Annual Emissions Due to Harvest ($MMtCO_2e$/year)
	Poorly Stocked Stands	Moderately Stocked Stands			
Scenario 1	164,975	0	3.21	0.09	11.24
Scenario 2	164,975	347,813	14.44	0.47	51.24
Scenario 3	164,975	695,625	25.68	0.85	91.05

tC = metric tons of carbon; $MMtCO_2e$ = million metric tons of carbon dioxide equivalent.

The targeted acreage is then assumed to be replanted in fully stocked plantations, such that carbon sequestration in these acres occurs at a rate consistent with average carbon sequestration in these fully stocked stands in PA. Acres replanted in one year continue to sequester carbon in subsequent years, so the carbon sequestered in a given year is calculated as the sum of carbon 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 carbon storage values are given in Table 5. Overall results of the analysis of carbon storage on replanted acres are given in Table 6.

Table 5. Forest Carbon Sequestration Rates in Conifer Forests

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

tC = metric tons of carbon

Table 6. C Storage on Restocked Acreage

Year	Scenario 1		Scenario 2		Scenario 3	
	Cumulative Planted Acreage	Annual Carbon Storage ($MMtCO_2e$/yr)	Cumulative Planted Acreage	Annual Carbon Storage ($MMtCO_2e$/yr)	Cumulative Planted Acreage	Annual Carbon Storage ($MMtCO_2e$/yr)
2013	164,975	0.~~2~~3	512,788	~~0.62~~0.975	860,600	1.~~04~~65
2014	329,950	0.~~4~~6	1,025,576	~~1.24~~1.95	1,721,200	~~2.08~~3.30
2015	494,925	0.~~6~~9	1,538,364	~~1.86~~3.00	2,581,800	4.95~~3.12~~
2016	659,900	~~0.8~~1.2	2,051,152	~~2.48~~3.90	3,442,400	~~4.16~~6.60
2017	824,875	1.~~0~~5	2,563,940	~~3.10~~4.86	4,303,000	~~5.2~~8.25
2018	989,850	1.~~2~~8	3,076,728	~~3.72~~5.85	5,163,600	~~6.24~~9.90
2019	1,154,825	~~1.4~~2.1	3,589,516	~~4.34~~6.65	6,024,200~~,~~	~~7.28~~11.55
2020	1,319,800	~~1.6~~2.5	4,102,304	~~4.96~~7.62	6,884,800	~~8.32~~13.20
Cumulative Totals	**1,319,800**	**~~7.2~~10.9**	**4,102,304**	**~~22.3~~34.8**	**6,884,800**	**~~37.44~~59.4**

$MMtCO_2e$ = million metric tons of carbon dioxide equivalent.

Table 7 illustrates that the overall GHG impact of this initiative in each year is calculated as the difference between emissions due to harvest and cumulative carbon storage on replanted acreage in that year. The numbers in Table 4 represent net emissions rather than net GHG benefit, because the one-time loss due to harvest in a given year exceeds the carbon sequestration on cumulative planted acreage in all years during this relatively short period of this analysis (2013–2020). As noted in Table 7, the rate of carbon loss associated with this initiative continues to decrease with time as the new forest establishes itself. If policy implementation is complete in 2020 and restocked land is allowed to continue to sequester carbon, it would take 32, 48, or 51 additional years, respectively, for carbon sequestration on restocked land to offset the one-time emissions from harvesting the under-stocked land in Scenario 1, 2, or 3.

Table 7. Net Carbon Emissions Associated with Achieving Fully Stocked Forest by 2020

Year	Scenario 1	Scenario 2	Scenario 3
	Net Carbon Emissions ($MMtCO_2e$/Year)		
2013	10.9411.1	50.326	89.40
2014	10.810.64	49.329	87.875
2015	10.534	48.331	86.10
2016	10.204	47.34	84.45
2017	9.974	46.437	82.80
2018	9.544	45.439	81.215
2019	9.214	44.441	79.650
2020	8.984	43.44	77.985
Cumulative Total	**79.1280.2**	**374.781**	**669.300**

$MMtCO_2e$ = million metric tons of carbon dioxide equivalent.

Economic Cost:

Costs associated with this initiative 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 $17.28/cubic meter ($m^3$), adjusted to $2010, while the cost to harvest a poorly stocked stand is $22.46/$m^3$ of volume (adjusted to $2010). The "poorly stocked" figure of $22.46/$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 at $716/acre in 2010.[1] This includes the cost of planting ($158/acre), plus seedlings ($105/acre), and herbicide ($137/acre) and. Ffencing for deer exclusion totals ($315/acre). For comparison, Sohngen et al. (2007) report an average cost of forest planting without deer exclusion of $405/acre in the Northeast, now estimated at $426 in $2010. 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 secondthird-quarter 2012 2013 stumpage prices from the Pennsylvania Woodlands Timber Market Report.[2] 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 for mixed oak, hard maple, soft maple, white oak and miscellaneous hardwood species, for an average price of $171.83118.60 per Mbf in 2013 dollars, or $110 in 2010 dollars. A 30% reduction factor of the price was used to account for differences in saw timber and pulpwood values, making it $77 per Mbf in 2010 dollars. Annual revenue from harvest was subtracted from the sum of the annual costs of harvesting and planting to determine the net cost under each scenario.

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

[2] Pennsylvania State University. The Pennsylvania Woodlands, Timber Market Report, Third quarter 201307 stumpage prices, Available at: http://extension.psu.edu/natural-resources/forests/timber-market-report/reports/2013/2013-3rd-quarter.

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 today's dollars (using a discount rate of 5%). Total discounted costs (cost savings) and levelized cost-effectiveness for restocking under-stocked forests in PA are shown in Table 8.

Calculations

Scenario 1 – 100% of poorly stocked forest

To calculate the cost of harvesting an acre, it depends on the volume of wood cut. For this analysis, we used an average volume of a poorly stocked forest of maple-beech-birch and oak-hickory as outlined in Table 3 and assume 21.8 m^3/acre of poorly stocked forest. Assuming harvesting costs of $22.46 /$m^3$ as discussed above, it would cost approximately $489.63 to harvest one acre of poorly stocked forest.

Using the same assumption applied above for the cost of harvesting, the average volume of a poorly stocked forest of maple-beech-birch and oak-hickory is 769.71 ft^3/acre. Given that one ft^3 equals to 12 board feet, there are 769.71 ft^3/acre x 12 board feet, or 9,236 board feet/acre. There are approximately 9.236 thousand board feet (Mbf) per acre of poorly stocked forest. At $77 per Mbf x 9.236 Mbf per acre, one acre of poorly stocked forest would fetch approximately $711 per acre.

Discounted cost

Subtracting the revenue generated ($711/acre) from the cost of harvesting and replanting ($489.63/acre + $716/acre) results in a net cost to harvest and replant one acre of poorly stocked forest of approximately $222.

$494 per acre x 164,975 acres per year = $81,497,650 cost of reforesting poorly stocked forest in Y1.

Scenario 2 - 100% poorly stocked forest + 50% of moderately stocked forest

For this analysis, we used an average volume of a moderately stocked forest of maple-beech-birch and oak-hickory as outlined in Table and assume a total of 44.45 m^3/acre for a moderately stocked forest. We assumed the cost to harvest a moderately stocked forest, is the median of the cost to harvest a poorly stocked forest and a fully stocked forest, making it $19.87/$m^3$. Assuming harvesting costs of $19.87/m3, it would cost approximately $883.22 per acre to harvest one acre of moderately stocked forest.

Using the same assumption applied above for the cost of harvesting, the average volume of a moderately stocked forest of maple-beech-birch and oak-hickory is 1,534.28 ft^3/acre. One ft3 = 12 board feet. (1,534.28 ft3/acre x 12 board feet) = 18,411 board feet/acre. There are approximately 18.411 Mbf per acre of moderately stocked forest. At $77 per Mbf x 18.411 Mbf per acre, one acre of moderately stocked forest would be worth approximately $1,417 per acre.

Discounted cost

Subtracting the revenue generated ($1,417/acre) from the costs of harvesting and replanting ($883.22/acre + $716/acre) results in a net cost to harvest and replant one acre of moderately stocked forest of approximately $182.

$182 per acre x 347,813 acres = $63,301,966 cost of reforesting 50% of moderately stocked forest in Y1.

50% of moderately stocked $63,301,966 + 100% of poorly stocked $81,497,650 = $144,799,616 cost in Y1.

Scenario 3 - 100% poorly stocked forest + 100% of moderately stocked forest
This calculation combines the calculations for scenarios 1 and 2.

Using the assumptions from Scenario 1, subtracting the revenue generated ($711/acre) from the cost of harvesting and replanting ($489.63/acre + $716/acre) results in a net cost to harvest and replant one acre of poorly stocked forest of approximately $494.

Using the same assumptions as Scenario 2, subtracting the revenue generated ($1417/acre) from the cost of harvesting and replanting ($883.22/acre + 716/acre) results in a net cost to harvest and replant one acre of moderately stocked forest of approximately $182.

Discounted Cost
$182 per acre of moderately stocked forest x 695,625 acres = $126,603,750 cost of reforesting 100% moderately stocked forest in Y1.
100% moderately stocked $126,603,750 + 100% poorly stocked $81,497,650 = $208,101,400.

Table 8. Discounted Costs ($2010) for Implementing the Harvest/Replant Strategy for Fully Stocking Under-stocked Acreage

Year	Scenario 1	Scenario 2	Scenario 3
2013	$81,497,650 ~~$53,804,567~~	$144,799,616 ~~$493,543,503~~	~~$933,282,438~~ $208,101,400
2014	$85,572,533 ~~$51,242,444~~	$152,039,596 ~~$470,041,431~~	$218,506,470 ~~$888,840,417~~
2015	$89,851,159 ~~$48,802,328~~	$159,641,576 ~~$447,658,506~~	$229,431,793 ~~$846,514,683~~
2016	$94,343,717 ~~$46,478,408~~	$167,623,655 ~~$426,341,434~~	$240,903,383 ~~$806,204,460~~
2017	$99,060,903 ~~$44,265,150~~	$176,004,838 ~~$406,039,461~~	$252,948,552 ~~$767,813,772~~
2018	$104,013,948 ~~$42,157,286~~	$184,805,080 ~~$386,704,248~~	$265,595,980 ~~$731,251,211~~
2019	$109,214,645 ~~$40,149,796~~	$194,045,334 ~~$368,289,760~~	$278,875,778 ~~$696,429,725~~
2020	$114,675,378 ~~$38,237,901~~	$203,747,600 ~~$350,752,153~~	$292,819,567 ~~$663,266,405~~
Cumulative Costs	$778,229,933 ~~$365,137,880~~	$1,382,707,298 ~~$3,349,370,496~~	$1,987,182,926 ~~$6,333,603,112~~
~~**Levelized Cost-Effectiveness ($/MtCO2e)**~~	~~$4.55~~	~~$8.94~~	~~$9.46~~

Implementation Steps:

- Work with PA NRCS and Forest Stewardship Program to integrate and package (Farm Bill) funding and technical assistance programs to emphasize forest carbon sequestration practices.
- Create a program to encourage forest landowners to consider forest certification by providing technical/financial support, aggregation services, and product marketing assistance.
- Expand forest certification to additional state agencies and public lands.

- Assess the feasibility of a "forest carbon leasing" program, whereby private forest landowners would be compensated for long-term rights/value of forest carbon on their properties.
- Create a state tax credit (perhaps modeled on Resource Enhancement and Protection [REAP]) for forest landowners who implement approved forest carbon enhancement practices on their lands. This also could extend to activities associated with the reforestation, afforestation, and regeneration work plan.

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:[3]

- *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 processing and collecting 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 BOF as assigned, coordinates the distribution of federal funds and equipment to local fire-fighting forces, acquires federal excess property to supplement BOF fire equipment, and 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. It develops forest pest information and technology development and transfer.

USFS Forest Stewardship Program: This program promotes the development of Stewardship Plans (10-year forest management plans) for private forestland. It is a BOF-wide program, delivered mainly by district Service Foresters. Policy and cost-coding procedures are administered through BOF's CFM Section (http://www.fs.fed.us/spf/coop/programs/loa/fsp.shtml).

Potential Overlap: None

Data Sources/References:

J.E. Smith et al. 2006. *Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States*, GTR NE-343. USFS Northern Research Station. (Also published as part of the DOE Voluntary GHG Reporting Program.)

[3] See: http://www.dcnr.state.pa.us/forestry/ffp/index.aspx.

Sohngen, B., et al. 2007. *The Nature Conservancy Conservation Partnership Agreement.* Part 4: "Opportunities for Improving Carbon Storage and Management on Forest Lands."
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.*
Pennsylvania State University. The Pennsylvania Woodlands' Timber Market Report, Third quarter 2007 stumpage prices, Available at: http://www.sfr.psu.edu/TMR/TMR.htm.
Sampson, R.N., S. Ruddell, and M. Smith. *Managed Forests in Climate Change Policy: Program Design Elements.* 2007. Available at: http://www.safnet.org/managedforests_final_12-14-07.pdf.
Nunery, J.S., and W.S. Keeton. 2009. Forest carbon storage in the northeastern United States: Net effects of harvesting frequency, post-harvest retention, and wood products. *Ecological Applications*, in review.
Pennsylvania DCNR, BOF. 2006. *Forest Products Statistical Report.* Available at: http://www.dcnr.state.pa.us/forestry/sfrmp/documents/ Timber_BOF_Forest_Prod_Stat_Report_2006.pdf.