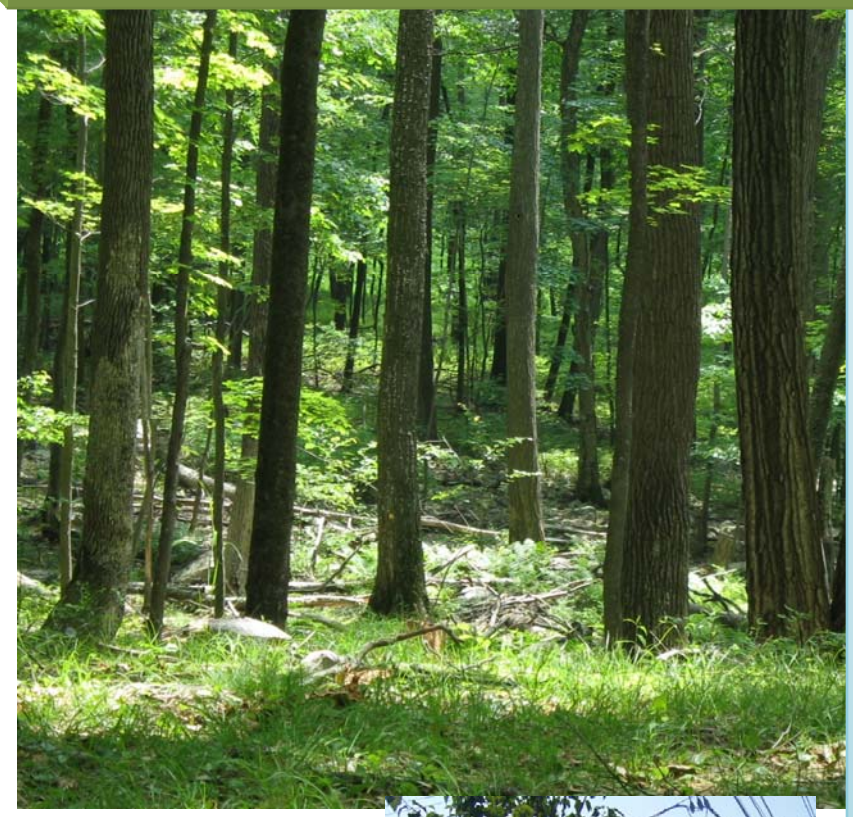
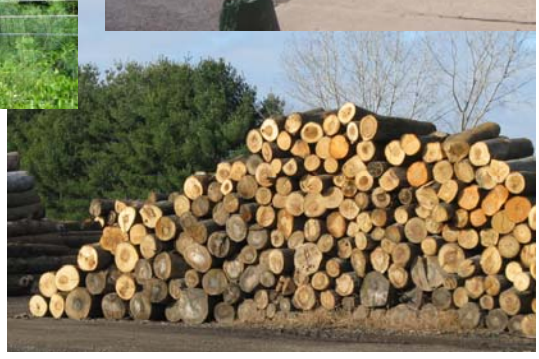
Assessing the Potential for New Jersey Forests to Sequester Carbon and Contribute to Greenhouse Gas Emissions Avoidance





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New Jersey
Department of Environmental Protection
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Assessing the Potential for New Jersey Forests to Sequester Carbon and Contribute to Greenhouse Gas Emissions Avoidance

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Assessing the Potential for New Jersey Forests to Sequester Carbon and Contribute to Greenhouse Gas Emissions Avoidance

Executive Summary

Section 1a: Organic carbon storage in the forest lands of the State of New Jersey

The overall objective of this section was to assess the quantity of carbon stored by New Jersey forests (i.e., carbon stock) and estimate the amount of carbon being sequestered annually. This assessment was accomplished through a combination of literature review, analysis of existing forest inventory and soil carbon data, and modeling of forest ecosystem dynamics. The USDA Forest Service Forest Inventory and Assessment (FIA) program served as a primary data source. This study provides a spatially explicit picture of carbon stock by presenting results by physiographic region. In addition, estimates were also undertaken (where feasible and appropriate) by other categorizations: forest type, rural vs. urban land use, private vs. public ownership. Major findings concerning the carbon stock:

- The standing forest biomass carbon stock for the year 2005 was estimated to be 75,840,966 metric tons[1] (with a range between 74,392,404 and 77,289,528).
- Increased standing forest carbon density caused by a maturing forest led to over an 85% increase in standing forest biomass carbon stock between 1987 and 2005.
- Taken on an annual basis, New Jersey forests increased carbon storage (in aboveground woody tissues) from a rate of approximately 1,711,440 tons/yr between 1987 and 1999 to approximately 2,416,560 tons/yr between 1999 and 2005.
- The area of forest statewide increased between 1987 (774,260 hectares) and 1999 (1,032,709 hectares) but then declined as of 2005 (996,821 hectares).
- The total carbon stock stored in New Jersey's forest is estimated to be approximately 172,846,595 tons (with a range between 128,615,661 and 225,832,875 tons). Of the total, standing trees accounted for 44%, soil accounted for 42%, down dead wood contributed 9%, and roots contributed 4%, and shrubs contributed 0.1%,
- Standing forest carbon density (tons C / ha) is often higher in urban areas than in rural areas suggesting that urban forests have an important role in carbon sequestration.

Computer modeling of carbon flux was undertaken to quantify carbon sequestration from vs. emission back to the atmosphere. As trees grow they remove carbon from the atmosphere and fix it in their tissues; as plants respire or plant materials decay, carbon is released back to the atmosphere. Major findings concerning the carbon flux:

- A typical New Jersey forest is predicted to reach its maximum carbon sequestration at 75 years with a density of approximately 150 tons/ha. After the peak growth stage, the amount of carbon stored in the forest stand starts to decline as the stand matures and thins in tree density. Assuming a 100 year time frame, we estimate approximately 140 tons/ha of carbon stored.

[1] Note that the units for the forest biomass and carbon stock are reported in metric tons (1 metric ton = 1000 kg or 2,204.6 lbs). The terms metric ton and ton will be used interchangeably.

- The carbon flux for the entire state's forests is estimated to be 1,068,942 tons per year.
- The Outer and Inner Coastal Plain forest reach a peak forest carbon density (tons C / ha) of 116 ton C/ha at around 69 years of growth. Based on the average age of forest stands (as recorded by the FIA data), the Inner and Outer coastal plain forests are close to the peak forest carbon density.
- Though the overall carbon density is generally lower, due to its large area of forest land, the Outer Coastal Plain plays an outsize role in the state's overall forest carbon dynamics.
- The Ridge and Valley, Highlands and Piedmont forests are estimated to reach their maximum carbon density between years 117 and 143 of growth with an estimated carbon density of over 140 ton C/ha.

While the IntCarb forest carbon dynamics model is useful in exploring various scenarios, it is still just a model (i.e., our best approximation of reality) and the results should be assessed with a certain degree of skepticism. Further empirical validation is needed to examine the comparative value of forest sequestration capacity, including forest soils, at various forest ages from young to old growth across a broad range of New Jersey conditions. Additional research is also needed to more fully characterize the degree of uncertainty in estimating carbon stock and flux estimates.

Section 1b: Soil organic carbon accumulation in young, post-agricultural forests of New Jersey

The overall objective of this section was to estimate soil organic carbon (SOC) stocks and calculated rates of soil carbon accumulation for recently abandoned agricultural land in New Jersey. More specific objectives were two-fold: (1) to provide a reasonable estimate of SOC accretion rates for young forests of New Jersey, and (2) to characterize general regional differences in SOC stocks and accretion rates among the state's physiographic provinces.

Our findings suggest that:

- Annual soil carbon accretion rates range between approximately 0.1-0.3 tons C /ha/yr (with a mean of 0.25 t/ha/yr) for young, post-agricultural forests of New Jersey. This translates to an average annual sequestration capacity of 10-30 tons for a 100 hectare field undergoing forest succession when taken over a 60 year time frame. These results demonstrate that soil carbon accumulation in young forests can make significant contributions to carbon sequestration projects.
- The highest carbon densities and the highest carbon accretion rates are in rural areas of the Inner & Outer Coastal Plain. Rates of carbon accumulation calculated from site pairs in the Piedmont, Highlands, and Ridge & Valley were mostly at or near the state-wide mean.
- Our results suggest that most soil carbon accretion following agricultural abandonment occurs in the litter layer and in the upper 10 cm of the soil profile. It is important to note that a considerable portion of the soil organic carbon present in these pools will be in highly labile forms, and thus lack the permanence necessary to contribute to long-term soil carbon sequestration. To gain a better understanding of long term soil carbon storage

separate estimates for the labile, passive, and recalcitrant soil carbon fractions must be derived.

While we have demonstrated that young forests on New Jersey soils are accumulating soil carbon, and shown some basic regional differences in carbon accretion rates, the considerable variation among the site pairs must be noted. While these preliminary results may provide a useful baseline for determining the sequestration potential of New Jersey's forest soils, future studies should include multiple replicates on fewer soil types to reduce sources of error and refine estimated soil organic carbon accretion rates. Efforts should also be made to locate forested sites of a similar community, and agricultural sites that have been subjected to comparable management regimes.

Section 2: Quantification of the capacity to sustainably produce wood-based biomass renewable energy in NJ and thereby reduce reliance on fossil-based non-renewable energy resources.

In order to determine the amount of wood-based biomass that could be sustainably produced in NJ and the resultant renewable energy production potential, an assessment of the major sources of wood was conducted. These included Class 1 type materials including; Forestry Residues, Primary and Secondary Forestry Products Industry Residues, Urban Forestry and Landscaping Residues, and Bioenergy Crops and Class 2 material which was from Construction and Demolition Waste sources. Once the maximum potential quantities of wood-based biomass was determined, the renewable energy production potential was determined based on the current efficiencies of the various appropriate conversion technologies. The total potential maximum annual bioenergy production for woody biomass sources (by type of energy) is estimated to be:

- 4,728 Gigawatt hours of electricity;
- 28,352 billion BTU's of heat; and,
- 163.2 million gallons of ethanol fuel.

The amount of fossil fuels displaced is estimated to be:

- 2,165 thousand tons of coal for electricity generation;
- 220.7 million gallons of #2 oil for heat production; and,
- 111.0 million gallons of gasoline for fuel.

It is important to note that these numbers represent an upward potential, a theoretical maximum of what might be produced, a ceiling to be used only for purposes of planning. New Jersey has many business development opportunities for wood-based bioenergy production. The information provided can be used as a resource for project developers looking to locate their business in New Jersey. In addition to the economic benefits of using NJ's woody biomass for energy production, there are many environmental benefits that could be realized from utilizing woody biomass as well.

Section 3: Identification and description of carbon sequestration projects that could serve as models for future projects in New Jersey

The objective of this section was to identify and describe existing projects suitable for replication in New Jersey for traditional and urban-community forest types. With increasing interest and activity in 'carbon offsets' and 'cap-and-trade' programs over the past several years, there has also been a steadily increasing interest in the area of forest-based carbon sequestration

and forest-based carbon offset programs. The recent years of economic downturn have slowed this increase somewhat, but substantial interest remains.

Despite the many forest carbon sequestration projects either currently being implemented, underway or contemplated, however, it is challenging to locate detailed and/or replicable projects. No 'turn-key' projects for replication were identified; however, there are existing projects to aid demonstration design. Regardless of site, the parameters of project duration, baseline determination, additionally, leakage, monitoring, verification, transparency and credibility can all be determined for projects using protocols from one of two registries: either the Northeast Regional Greenhouse Gas Initiative (RGGI) with the Maine Forest Service's Recommendations, or the Chicago Carbon Exchange (CCX).[2]

Section 4: Potential Income from the Sale of Carbon Offsets and Class I Renewable Energy Certificates

The sale of CO_2 offsets generated from carbon sequestration forestry projects in regional and national markets represents a significant potential revenue stream through the sale of the offsets. An offset represents the reduction of one ton of CO_2 from a specified mechanism. The current market is fairly limited with regards to carbon sequestration projects, but there is the potential for a large number of projects to be accepted by a number of markets in the future. The current and potential markets are described with a projection of potential income that can be realized from these markets.

- The market for carbon offsets, especially at a national level, is extremely uncertain and the carbon sequestration projects that will qualify as offsets are unknown. The regional market is already in place and trading has occurred for a few years, but the national market is still in the infant stages of discussions.
- The markets that are in place and the projects that qualify determine the amount of potential income from the sale of CO_2 allowances.
    - If a national market is in place and multiple facilities qualifying for offsets the potential income could be significant. For example, if 5% of New Jersey's rural forest land (32,781 hectares) qualifies for sequestration projects the potential income ranges from $41 million to $109 million through 2050 depending on the discount rate.
    - If only a regional market is in place the potential income is significantly less. If 5% of New Jersey's forest land qualifies for sequestration projects the potential income ranges from $3.7 million to $7.7 million through 2050 depending on the discount rate.
- The revenue stream for Class I REC's is more certain, but the potential capacity installed is very uncertain. If 5% of the potential capacity can be built (84 MW) the income generated from the sale of Class I RECs ranges from $91 million to $108 million through 2020 depending on the discount rate.

[2] CCX may no longer be active.

Section 1a: Organic carbon storage and flux in the forest lands of the State of New Jersey

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Introduction

New Jersey contains several extensive areas of forest land. In addition to their critical role in the carbon cycle, these forests also provide such vital ecosystem services as watershed protection, wildlife habitat, and recreation, to name just a few (Millenium Ecosystem Assessment, 2005a; Costanza, et al., 2006; NJDEP, 2007). For many decades, forest land has been the most prevalent landscape category in the state occupying more areas than any other land use category. Recent decades, however, have seen deforestation in New Jersey accelerate largely due to sprawling residential and commercial development (Hasse and Lathrop, 2008). Urban growth consumed over 3,000 hectares of forest land per year between 1995 and 2002. This continuing loss of forest land and potential consequences in the regional carbon cycle highlights the need for better information about the current status of carbon storage in New Jersey's forests.

While scientific understanding of the role of forests in the global carbon cycle has increased in recent years, there is still a significant lack of information on the storage of carbon within selected forest components (e.g., belowground biomass) and specific geographic regions. Current information about carbon storage in New Jersey has several limitations such as lack of information on selected forest components and specific geographic regions. Some results lack spatially explicit information. Trees remove (or fix) carbon from the atmosphere during the process of photosynthesis and incorporate this carbon into their tissues (or biomass), thus effectively storing (or sequestering) this carbon for extended periods of time. Organic carbon stored in forests includes both aboveground and belowground components. Aboveground biomass can be partitioned into standing live trees, standing dead trees, shrub, and down dead wood (DDW). DDW includes coarse wood debris and fine wood debris. The belowground component includes roots and organic material incorporated into soils. This movement from the atmosphere into biomass and back out due to the processes of respiration and decay is termed flux. Of critical importance is the sign and magnitude of this flux, i.e., is there a net positive flux into long term storage. Improved quantification of organic carbon storage and flux in forest biomass will help illuminate the degree to which New Jersey forests can reduce statewide greenhouse gas emissions and contribute to emerging carbon markets.

Our overall objective was to assess the quantity of carbon stored by New Jersey forests and estimate the amount of carbon being sequestered annually. This assessment was accomplished through a combination of literature review, analysis of existing forest inventory data, and sampling/analysis of soil carbon. Existing carbon accounting methods such as those provided in the USEPA workbooks (USEPA, 1995; NJDEP, 1996) while providing a useful starting point, are generally aspatial in nature. Our assessment is spatial in nature providing information at county level and finer scales. More specifically, our objectives were to:

1. Estimate, within the state of New Jersey, the carbon stocks stored in the various forest components, specifically in the above-ground biomass (including the standing trees (live

and dead), the understory/shrub layer, down dead wood (DDW); and the belowground biomass, including root biomass and organic carbon in soils. These estimates will seek to characterize the following for each of the five sub-components:

   a. Carbon stock per unit of land area (i.e., the quantity of carbon stored in weight per unit area) for each of these components and sub-components; and
   b. The annual carbon flux (i.e., net annual sequestration of carbon, in weight per unit area); and

2. Summarize the above estimates of carbon stock as statewide totals but also in terms of various geographic zones including:
   a. Physiographic region (as defined by the New Jersey Geological Survey);
   b. Rural vs. urban areas (as defined by the United States Census Bureau); and
   c. Publicly vs. privately owned lands (as defined by the New Jersey Department of Environment Protection (NJDEP) Geographic Information Systems (GIS) data); and,
   d. Major forest types (as defined by the United States Department of Agriculture (USDA) Forest Service and Society of American Foresters (SAF)).

Methods

Quantifying Carbon contents: Above and below-ground-ground biomass

To quantify the amount of stored carbon in the above-ground components of New Jersey forests, we relied primarily on data collected by the USDA Forest Service's Forest Inventory and Analysis (FIA) Program (USDA Forest Service, 2006). The FIA database provides the most comprehensive information available on the status and trends of our nation's forest lands, including those of New Jersey. USDA FIA program defines forest land as land that is least 10% stocked with trees of any size, or that formerly had such tree cover and is not currently developed for nonforest use. The minimum area for classification as forest land is 1 acre. The FIA data are developed from an extensive network of ground sample plots and provide detail on the standing live and dead trees, as well as understory vegetation, and down woody debris attributes. These data have undergone a rigorous quality assessment and evaluation protocol and statistical methods have been applied to quantify the degree of uncertainty/reliability of the data. These data are available from the FIA program in a variety of formats, for example, summarized by state and county or by sample plot. We accessed the summarized data through the online tools developed as part of the **F**orestry **I**nventory **D**ata **O**nline (FIDO), as well as the inventory data for individual sample plots using the tools available through the Forest Inventory and Analysis Data Base (FIADB) Datamart website (http://www.fia.fs.fed.us/tools-data/default.asp). These data were analyzed and synthesized in order to quantify the amount of carbon stored in above-ground biomass in the state to address the assessment objectives detailed above.

While these existing tools provide some of the necessary information to address the objectives outlined above on carbon stocks and fluxes, additional analyses were required to more fully address all forest components. In particular, additional GIS analyses were performed in order to characterize forested regions by physiographic regions or urban vs. rural areas. For example, the FIA data is presently summarized by county or ownership but not by physiographic region or urban vs. rural area. However, to protect the privacy of individual forest landowners, the USDA Forest Service does not release the exact coordinate locations of the FIA sample plot

locations. Thus individual researchers are limited in conducting their own independent GIS-based analysis using only the publicly-available FIA data. To obtain FIA data classified by physiographic region, by rural vs. urban area and by public vs. privately owned land, we worked with the FIA Spatial Data Services (http://www.fs.fed.us/ne/fia/spatial/index_ss.html) to conduct these customized queries.

Additionally we supplemented the FIA data with other forest inventory data sets where available. For example, co-Principal Investigators Lathrop and Edwin Green have collected data from 150 forest inventory plots in the Ridge and Valley and Highlands physiographic regions of the state. Additional forest inventory data sets were obtained for the Pinelands through the USDA Forest Service Pinelands Research Station and the Pinelands Commission Science Office.

For the below-ground components of New Jersey forests, we relied primarily on USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database.

The following graphic (Figure 1) provides an overview of the data sets employed to conduct our assessment, and the following sub-sections provide detail on the methodologies employed, using this data, to carry out the carbon storage assessments and depict the results geographically.

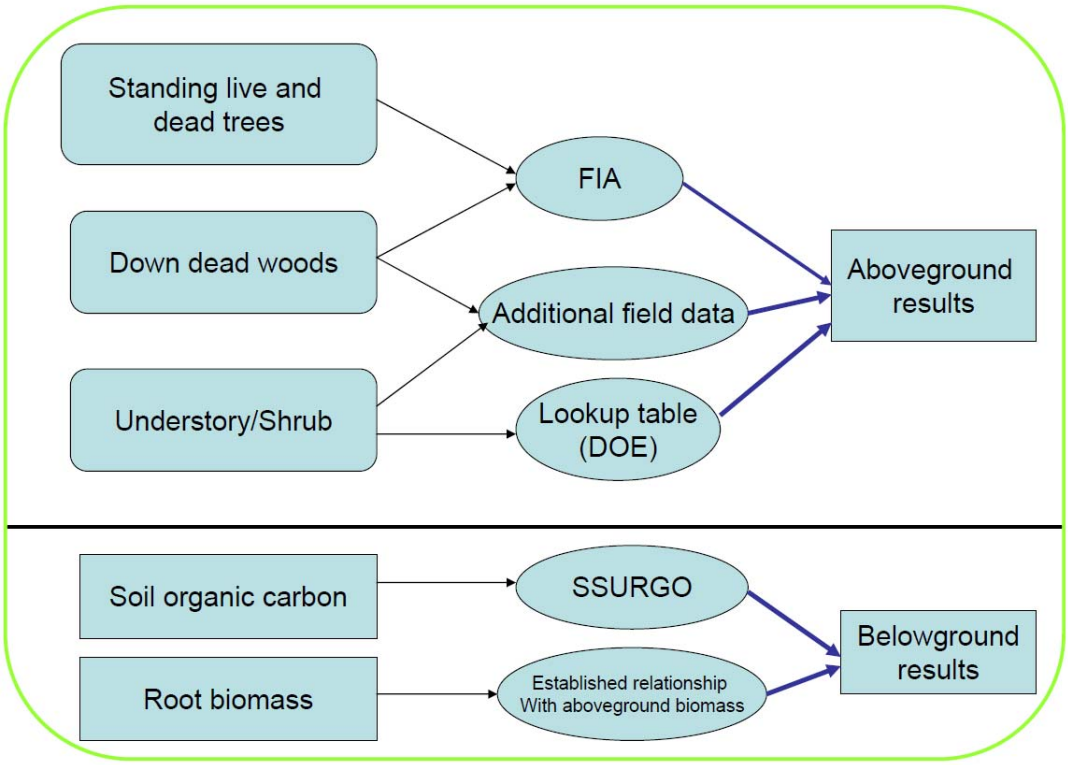

Figure 1. Method flowchart

1.1 Carbon stored in standing forest biomass (including live and dead trees)

1.1.1. Calculation of amount carbon stored in the standing forest

The amount of stored carbon in the standing forest was calculated for 2005, 1999, and 1987. The calculation procedure begins with downloading the relevant FIA data from the FIA website. The

relevant variables include [Tpacurr], [Drybiot] and [Expvol]. [Drybiot] is the total gross biomass oven dry weight including all tops and limbs from tree table in the FIA data. [Tpacurr] is the number of trees per hectare. [Expvol] is the area represented by each plot. Based on the FIA user manual "population estimates of total volume or biomass area calculated by summing the product of TPACURR, per tree values, and the appropriate area expander from the plot table" (U.S.D.A. Forest Service, 2006), the calculation process is comprised of three steps:

(1). [Vol] = [Tpacurr] * [Drybiot] to calculate biomass (in metric tons) within each part of a plot. This step calculates the biomass for the part of the plot the tree represents.

(2). The [Vol] of each portion of the plot was summed to get [sumofvol] which is the amount of biomass per plot. This step summarizes each part from the last step to result in biomass for each plot.

(3) [Totbio] $= \sum_{i=1}^{n} [Expvol] * [sumofvol]$ where n is the total plot number.

Estimates of total forest biomass were then converted into carbon storage (dry biomass carbon content) using the 50% rule (Raich et al., 1991; Brown and Lugo, 1982). Note that the units for the forest biomass and carbon are reported in metric tons (1 metric ton = 1000 kg or 2,204.6 lbs) per hectare. The terms metric ton and ton will be used interchangeably.

The confidence interval for the amount of carbon stored in the standing forests was based on accuracy standards of FIA data (USDA, Forest Service, 2006). FIA sampling procedures are designed to meet a mandated error on forest acreage of 3% per 1,000,000 acres of forest at 67% confidence level (*i.e.*, one standard error) (see Forest Service Handbook FSH 4809.11). This yields an error of 30,000 acres for an estimated total of 1,000,000 acres (i.e., 0.03 × 1,000,000 = 30,000). When estimates are derived for different size areas, the error percent must be appropriately scaled. Let p_i = error percent for an area of size A_i. Then if A_1 = 1,000,000 acres, p_1 = 0.03, or 3%, as per the USDA Forest Service standard mentioned above. Bechtold and Patterson (2005) show that the error percent for an area of size A_2 can be estimated as $p_2 = p_1\left(\frac{A_1^{0.5}}{A_2^{0.5}}\right)$. We used this method, with the caveat that A_1 was converted from 1,000,000 acres to 404,858 hectares. USDA FIA estimated there to be 774,260 hectares of forest land in 1987, 1,032,709 hectares of forest land in 1999 and 996,821 hectares of forest land in 2005 for state of New Jersey (Table 1). The sampling error for each year would be 2.17% (3% * $(404{,}858)^{.5}/(774{,}260)^{.5}$) in 1987, 1.87% in 1999 and 1.91% in 2005. Using the same method as calculating forest biomass carbon stock in 2005, forest biomass carbon stock in 1987 and 1999 were calculated.

1.1.2 FIA data request by alternative land divisions based on FIA plot location

In summarizing standing forest biomass for each physiographic region and urban/rural division, a custom data request was submitted to the FIA data center to extract standing forest biomass data by physiographic regions, Rural/Urban boundary and public vs. private ownership using the FIA plot data. Physiographic regions include OCP: Outer Coastal Plain, ICP: Inner Coastal Plain, P: Piedmont, N: Highlands, and RV: Ridge and Valley (Fig. 2) (NJGS, 2002). The urban boundary, as determined from US Census 2000 data, includes Urbanized area (UA) and Urban cluster (UC) as urbanized areas with a population size greater than 5,000 (U.S. Census Bureau, 2002). These urban land designations were delineated based on a census block which is the smallest census geographic unit. Any lands classified as forest land by the FIA within the

U.S. Census defined urban boundary were considered as urban forest. These forest lands may be on both public lands (i.e., parks) or private land. The classification and mapping of publicly owned vs. private forest lands was determined by the use of publicly owned open space areas based on NJDEP Green Acres digital GIS data (NJ Green Acres, 2004). Due to the constraints imposed by the spatial distribution of the plot locations as well as the confidentiality of the individual FIA sample plots, only approximate estimates could be obtained for carbon stock estimates for these alternative land divisions. Different area expansion factors were required and the total area for these alternative land divisions did not sum to equal the total forest area as estimated by FIA.

The total standing forest biomass was calculated as the sum of biomass in each land division (e.g., physiographic region) and was used to validate our standing forest biomass calculation using the previously described calculation (Steps 1-3 above). Mean stand age for each plot was retrieved from the FIA plot condition data and overall mean stand age was calculated for each physiographic region.

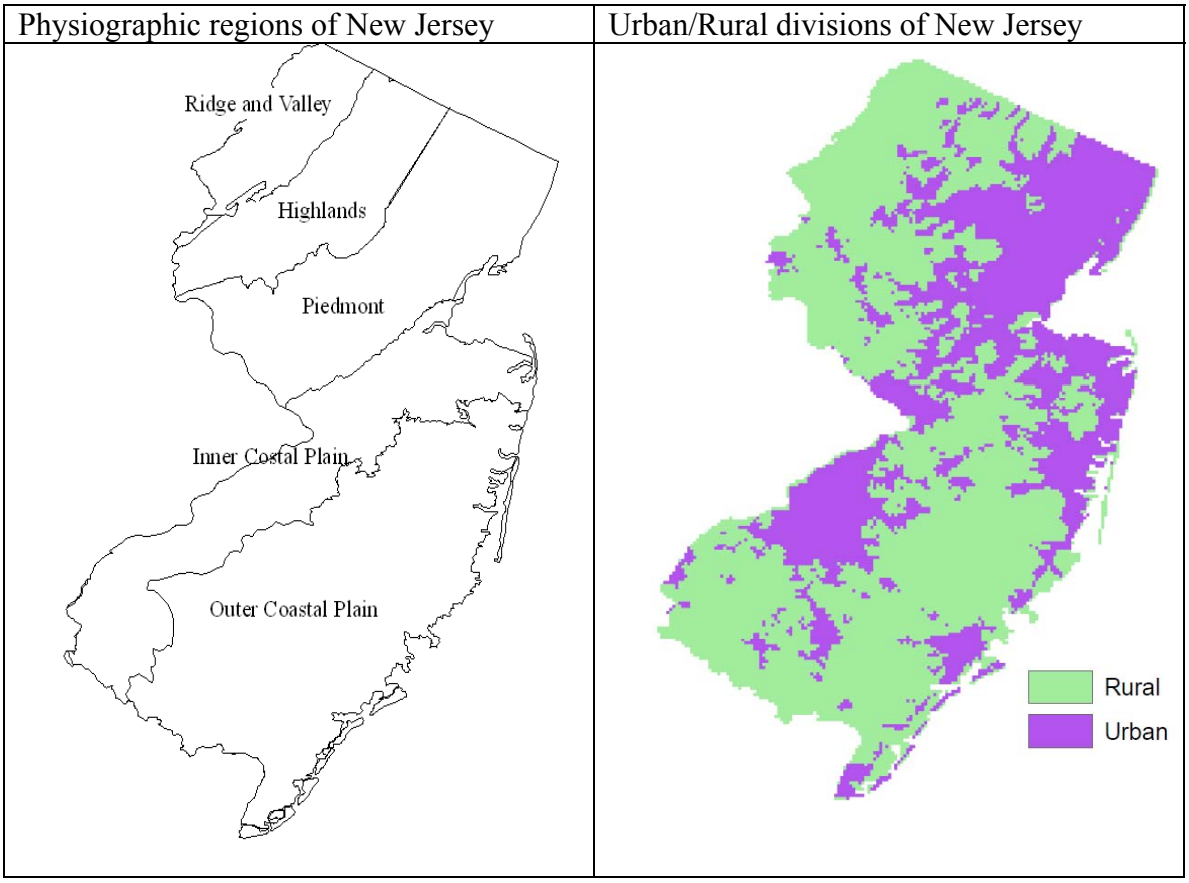

Figure 2. Physiographic regions and Rural/Urban divisions in New Jersey

1.1.3 Independent field sampling

The standing biomass estimates calculated using the FIA data were validated by independent field inventories where these data were available. The US Forest Service has conducted intensive field inventories in the Pinelands of New Jersey and these data were made available for our use. Three plots sized 1 km^2 were set up at three types of forests (Oak/pine, Pine/oak and Pine/Scrub oak). Tree and shrub biomass were intensively surveyed on each plot (Skowronski, et al., 2007).

1.2. Shrubs

Shrubs are defined as multiple-stemmed woody plants that are usually under 5-6 meters in height. The limited inventory data on shrubs required a different approach to calculating carbon stock in shrub as that applied to trees. We calculated shrub carbon density based on a lookup dataset which has established shrub biomass as determined by physiographic region, forest type and stand age. The lookup table was released by the greenhouse gas emission program (Department of Energy, 2006), and each parameter was established based on FIA inventory data and model simulations for various regions of the US. We employed the look-up table developed for the Northeast states which included states from West Virginia to Maine. Shrub carbon density for various types of forests and stand ages was retrieved from the lookup table. Shrub carbon storage was calculated based on carbon density.

1.3. Dead Down wood (DDW)

The existing FIA data available for the state of New Jersey includes only 20 DDW sampling plots across the entire state. The FIA DDW includes coarse woody debris (CWD), duff, litter, fine wood debris (FWD), microplot fuel, and residual fuel (Woodall and Monleon, 2007). [DDD carbon stock] is equal to:

C_FWD_10HR_MASS + C_FWD_100HR_MASS + C_CWD_MASS + C_SLASH_MASS.

[Forest Floor carbon stocks] is equal to:

C_DUFF_MASS + C_LITTER_MASS + C_FWD_1HR_MASS.

We calculated down wood carbon as: [Downed dead wood carbon stock] + [Forest Floor carbon stocks].

Previous studies have reported that down dead wood biomass varies with field plot conditions such as stand age, forest ownership and forest type (Chojnacky and Heath, 2002). In this study, we first established a statistical relationship between DDW and plot conditions and then applied this relationship to interpolate DDW value for the sites with no FIA field sampling coverage.

Plot condition information was retrieved from plot condition table of FIA data. In the model, average DDW biomass was the dependent variable. Ecoregion and ownership were independent dummy variables. Stand age was the other independent variable. The model resulted in a p-value of 0.0843 and R-square of 0.3367, which suggests that while the model is statistically significant (at an α of 0.5) it does not explain a high degree of the parameter variability. The relationship equation between DDW biomass and independent variables is:

DDWcarbon = 6.48043 + (-1.48282 * ownership) + (-4.17601 * Ecoregion) + 0.07982 *Stdage,

where the ownership and Ecoregion are dummy variables. The resultant model was applied to the entire state and DDW for forest land was calculated. The point file of DDW density calculated by plot from model prediction was converted into Thiessen polygons and then

converted into grid file. The 95% of confidence interval was calculated as (Max-Min)/6. This method relies on the fact that 99% of observation from a normal distribution area within about 3 standard deviations of the mean, so the range is approximately 6 standard deviations in length.

1.4. Soil carbon

While the soil has the potential to sequester carbon reliably for very long periods of time, it accretes very slowly, compared to the growth of forest trees. It is likely that for mature forests, soil carbon stocks are at an approximate steady state, and little new sequestration can be expected over timescales relevant to a carbon credit program (Odum, 1966). For mature forests, it is possible to estimate the amount (or stock) of soil organic carbon (SOC) per unit of forest land for different cover types from the data available from USDA Natural Resources Conservation Service (NRCS) Soil Survey Geographic (SSURGO) database (2008).

We summed the SOC content of each soil horizon over a 100-cm depth to determine the SOC content in each map unit. We calculated soil organic carbon density for each unit using a well established equation (Guo, et al., 2006):

SOC (tons/ha) = OM * BD * Volume * 0.58 * [rockfree] * f,

where the OM is organic matter content, BD is bulk density, Volume = depth (1m) * map unit area, the f converts SOC to tons/ha, and 0.58 converts organic matter to organic carbon.

The SSURGO data has minimum and maximum values in addition to a representative value for each soil property measurement (SSURGO, 1995). We used the representative value to calculate soil carbon and the upper and lower limit values to calculate error bounds around our estimate.

The polygon file of soil carbon calculated from SSURGO was converted into grid file, non-forest land masked out and then summarized by urban/rural and physiographic regions. Carbon density by urban/rural, and by physiographic regions was calculated as average carbon density in each land division. Carbon content was determined by the area in each land division multiplied by the carbon density.

1.5. Root biomass carbon

Root biomass is difficult to measure in the field. Normally it is estimated based on its relationship with other tree parts. For example, fine roots biomass (FROOT) have been found to have a solid relationship with DBH and it can be estimated as:

FROOT = EXP(- 5.888+2.039 * ALOG(D))

(Cairns, et al., 1997). A global data summary established the strong dependence of root biomass density (RBD) on aboveground biomass density (ABD), with a value of 0.26 ranging between 0.18 (lower 25% quartile) and 0.3 (upper 75% quartile). Their linkage can be expressed by an equation:

RBD (tons/ha) = exp[-1.085+ 0.926 Ln(ABD)]

where R-square is 0.83

(Cairns et al., 1997). This study adopted this established relationship and calculated root biomass by each ecoregion.

Since the root biomass carbon calculation was based on its relationship with aboveground biomass carbon, we calculated its confidence interval utilizing the same method as calculating that of aboveground biomass carbon, which is based on sampling error standard requirement of FIA data. The sampling error for 2005 would be 1.91% in 2005.

Quantifying Carbon flux

Annual carbon flux was simulated using a forest ecosystem carbon flux model, IntCarb (Song and Woodcock, 2003). IntCarb combines components from a forest population dynamics model (ZELIG) (Urban, 1990) and a terrestrial ecosystem biogeochemical process model (CENTURY) (Parton et al., 1993) to simulate forest development and heterotrophic respiration, respectively. The IntCarb model, by focusing on forest ecosystem processes, has overcome the common weakness of other terrestrial ecosystem models that use a limited number of biomes to represent vast areas and ignore potentially significant variation within biomes in terms of productivity. IntCarb simulates ecosystem carbon cycling by connecting forest stand level population dynamics and ecosystem biogeochemical process. In a simulation, first forest stand dynamics are simulated at a one-year time step. Relevant population dynamic processes such as individual tree establishment, regeneration, and mortality, and environmental stress such as drought and nutrient limitation are simulated. Then the growth is distributed to each tree component (leaves, branches, stems, fine and coarse roots) as driven by ecophysiological characteristics of each tree component and environments. The annual growth then enters the decomposition process.

IntCarb was parameterized for the five New Jersey physiographic regions to account for broad scale variations in climatic conditions, soil water capacity, soil fertility, and forest species composition (Supp. table 1-5). A spatially explicit "wall-to-wall" simulation was not undertaken but rather average conditions for each of the five physiographic regions were used. Parameterizing IntCarb for the other geographic zones under consideration (e.g., urban vs. rural or public vs. private) was not feasible, thus the carbon flux for these other geographic jurisdictions were not estimated. A 30-year record of monthly precipitation and temperature (from 1979 to 2008) downloaded from http://climate.rutgers.edu/stateclim_v1/data/index.html was used to derive monthly mean and standard deviation of precipitation and temperature. Based on soil features in each ecoregion, soil field capacity, wilting point and soil fertility were ranked from high to low as Ridge and Valley > Piedmont > Highlands > Inner Coastal Plain > Outer Coastal Plain (SSURGO, 1995). A list of dominant species for each physiographic region was developed based on personal familiarity with the forest species composition by co-PI Lathrop. For each simulated forest species, parameter variables incorporated include maximum age, maximum diameter, maximum height, annual growth rate, minimum degree day limit, maximum degree day limit, shade tolerance, soil moisture tolerance, nutrient stress tolerance and seeding ability (Supp. Table 1-5). The maximum age, maximum diameter, maximum height and annual growth rate are variables driving tree growth. The minimum degree day limit, maximum degree day limit, shade tolerance, soil moisture tolerance, nutrient stress tolerance and seeding ability are variables controlling potential seedling establishment. The values for each parameter variable were taken from literature data (Pastor and Post, 1985).

IntCarb was run first for 600 years as a spin run to reach a steady state, from which initial above-and below-ground carbon content was determined. With initial values obtained from the first spin run, IntCarb was run for another 300 years and then carbon density for each stand age in each physiographic region was estimated. Stand age was derived from FIA data which has stand condition information. Average stand age was calculated for each ecoregion. Forest area for each ecoregion was calculated from land use/land cover data inferred from remote sensing data (Hasse & Lathrop, 2008). Live biomass carbon stock in each physiographic region was calculated as forest area in each ecoregion times corresponding carbon density. Annual carbon flux was estimated as the accumulated carbon difference between two consecutive years. The

IntCarb carbon density estimates (tons C / ha) were compared with FIA-derived estimates (for a stand of mean age) for each physiographic region to validate the model outcome.

Results

2.1.1 Standing forest biomass carbon (including live and dead trees)

We estimated the standing forest biomass for the entire state of New Jersey for our baseline year of 2005 to be 151,681,932 metric tons and carbon content to be 75,840,966 metric tons. Based on the sampling error standard of FIA data, we estimate the standing forest biomass carbon content in New Jersey forest to range from a low of 74,392,404 to a high of 77,289,528 tons. New Jersey forests appear to be aggrading (i.e., increasing their carbon stock) (Fig. 3). Increased biomass density caused by a growing forest, as well as increased forest coverage from 1987 to 1999, though slightly declining in 2005, led to an overall increase in standing forest biomass between 1987 and 2005. The aboveground standing forest biomass carbon stock was estimated to be 40,804,634 tons with a range between 39,919,173 and 41,690,095 in 1987, 61,341,639 tons with a range between 60,194550 and 62,488,728 in 1999 and 75,840,966 tons with a range between 74,392,404 and 77,289,528 in 2005 (Fig. 3). The sampling error was 885,461 tons in 1987, 1,147,089 tons in 1999 and 1,448,562 tons in 2005. Taken on an annual basis, New Jersey forests increased carbon storage (in aboveground woody tissues) from a rate of approximately 1,711,440 tons/yr between 1987 and 1999 to approximately 2,416,560 tons/yr between 1999 and 2005.

Average stand age increases across the three time periods, from 54 years in 1987 (standard error of 2.8), 59 years in 1999 (standard error of 2.6), and 69 years (standard error of 4.2) in 2005 (Figure 3). The average biomass of each individual tree (tree drybiot, kg/tree) has increased over the time period of record, from 236 kg per tree in 1987 to 252 kg in 1999 and 270 kg in 2005 (Table 1). Based on forest coverage data from the FIA, forested area (Exparea) increased between 1987 and 1999, then proceeded to decrease slightly in 2005 (Table 1).

Table 1. Change in FIA factors related to standing forest biomass from 1987 to 2005.

	1987	1999	2005
Tpacurr	21.8	16	16.15
Tree drybiot (kg/tree)	236	252	270
Exparea (km^2)	7,740	10,327	9,968

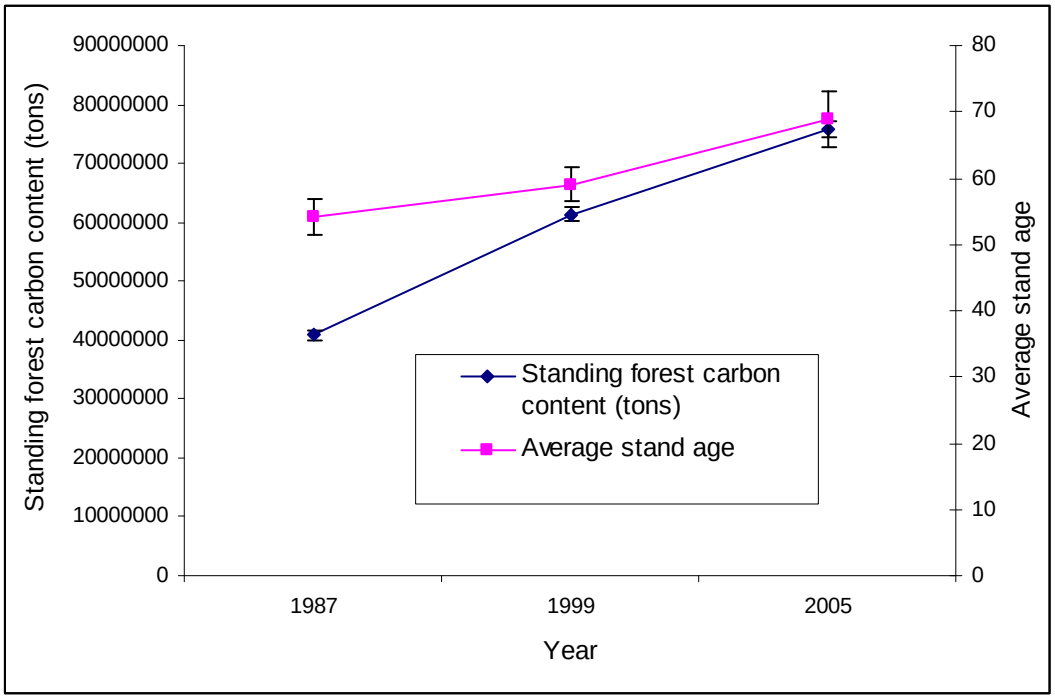

Figure 3. Dynamics of standing forest biomass carbon content and average stand age for New Jersey forests from 1987 to 2005.

Aboveground standing biomass carbon density was classified into six levels as: <20, 20-30, 30-60, 60-90, 90-125, and > 125 tons/ha (Table 2, Figure 4). Forests in the 30-60 tons/ha range represented approximately over one third of the forest area. As forests continued to mature from 1987 to 2005, the area categorized as the highest level of carbon density (>125 tons/ha) has increased from 2% in 1987 to 7% in 1999 and to 14% in 2005 (Table 2). Areas classified as the second highest carbon density increased from 6% in 1987 to 12% in 1999 and to 20% in 2005.

Table 2. Area (ha) for each range of standing forest biomass carbon density.

Carbon density (tons/ha)	Area 1987 (ha)	Percent	Area 1999 (ha)	Percent	Area 2005 (ha)	Percent
<20	81,384	11	153,030	15	48,433	5
20-30	131,185	17	96,972	9	72,540	7
30-60	287,567	37	369,206	36	349,328	35
60-90	213,233	28	211,531	20	195,402	20
90-125	47,039	6	127,710	12	194,677	20
>125	13,752	2	74,259	7	136,441	14
	774,160	100	1,032,709	100	996,820	100

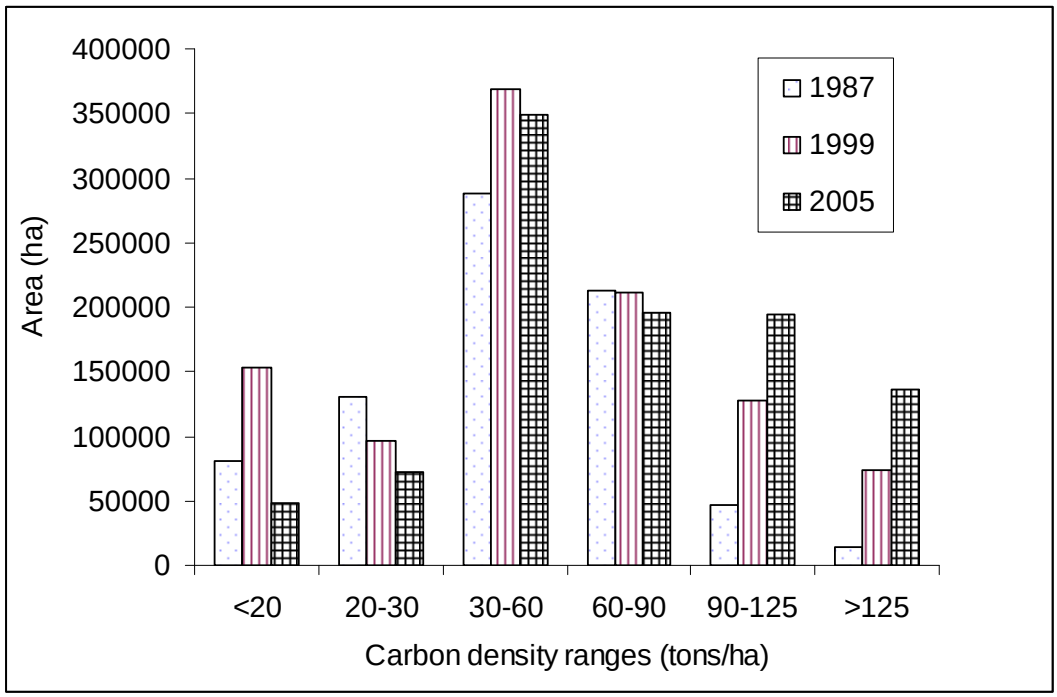

Figure 4. Area (ha) for each range of standing forest biomass carbon density (tons/ha).

The U.S. Forest Service plot data for three typical Pinelands forest types, conducted independently from FIA data at the Pinelands of the Outer Coastal Plain eco-region, displays a range in standing biomass carbon density from a low of 32.7 to a high of 83.1 tons/ha (Table 3). The mean forest biomass carbon density for the three sites is 38 tons/ha. The FIA-derived estimates for the Oak/pine forest biomass carbon density at the Outer Coastal Plain eco-region is 38.6tons/ha. This close correspondence in the results provides further confidence in the validity of our FIA-derived estimates of forest biomass carbon content in New Jersey.

Table 3. Tree biomass (tons) from additional field sampling independent from FIA inventories in NJ Pinelands (Skowronski, et al., 2007)

	Oak/Pine	Pine/Oak	Pine/Scrub Oak
Overstory			
Canopy height (m)	13.5 ± 1.2	10.5 ± 1.9	8.7 ± 0.9
Basal area (m^2 ha^{-1})	15.7 ± 3.8	11.5 ± 5.2	9.7 ± 3.7
Tree biomass (t ha^{-1})	83.1 ± 21.5	47.6 ± 25.5	32.7 ± 16.7

2.1.2. Aboveground standing forest carbon summarized by Rural/Urban division, by physiographic regions, public/private land and by forest types.

Standing forest biomass carbon density (tons/ha) varied by physiographic regions and Rural/Urban division. Piedmont and Highlands showed a higher standing forest biomass carbon density than other physiographic regions. The Outer Coastal Plain had the lowest forest biomass carbon density. It is interesting to note that urban forest had an average carbon density of 114 tons/ha which was higher than the 91 tons/ha of rural forest (Fig. 5). With its extensive areas of

forest (Fig 6), the rural Outer Coastal Plains had the highest standing forest biomass carbon storage, followed by rural northeast Highlands.

Due to the constraints imposed by the spatial distribution of the plot locations as well as the confidentiality of the individual FIA sample plots, only approximate estimates could be obtained for the breakdown in carbon stocks of urban vs. rural or public vs. private lands. Due to this limitation, the total area for the sum of the rural and urban forest or the sum of the public and private forest lands does not equal the total forest area as estimated by FIA (e.g., 9,968 km^2 or 996,800 ha in 2005, Table 1). The total area classified as rural forest was 655,630 ha and urban forest land was 140,697 ha (total area = 796,327 ha). Note that the FIA did not have any plot data within the urbanized zone of the Ridge & Valley or the Inner Coastal Plain physiographic provinces and thus no biomass estimates were available for urban forests within these two physiographic provinces. Rural forest had a total carbon storage of 60,455,518 tons which was four times that of urban forest (Fig 7). Based on the FIA results, privately owned forest land was estimated at 347,644 ha and publicly owned forest at 208,149 ha (total area = 555,793 ha). The standing forest on private land was estimate to store 48,027,513 tons of carbon, which is greater than that on public land (28,452,660 tons) (Fig. 8).

The FIA records forest inventory data summarized by USDA forest types. Note that the nomenclature for these forest types is based on a nationwide system and does not always match the names used by local state agencies. The USDA forest types that occur in New Jersey are the following: Lobshort: Loblolly / shortleaf pine group, in NJ locally referred to as pitch/shortleaf pine or PitchShort; Pinjun: Pinyon / juniper group, in NJ referred to as VirginiaRedCedar; OakPine: Oak / pine group; OakHic: Oak / hickory group; OakgumCyp: Oak / gum / cypress group, in NJ locally referred to as CedarMapleGum; ElmAshCot: Elm / ash / cottonwood group, in NJ locally referred to as ElmAshPoplar; MapBeeBir: Maple / beech / birch group. Oak/hickory (OakHic) is the main forest type in New Jersey and its standing biomass carbon stock comprises of 54% of that of the entire state (Fig. 9). The next largest forest group is maple/beech/birch group which makes up another 16%. The third largest group is loblolly/shortleaf pine group (in New Jersey locally referred to as pitch/shortleaf pine or PitchShort) which forms another 13.7%. The three primary groups make up 85% of the standing forest carbon stock in New Jersey.

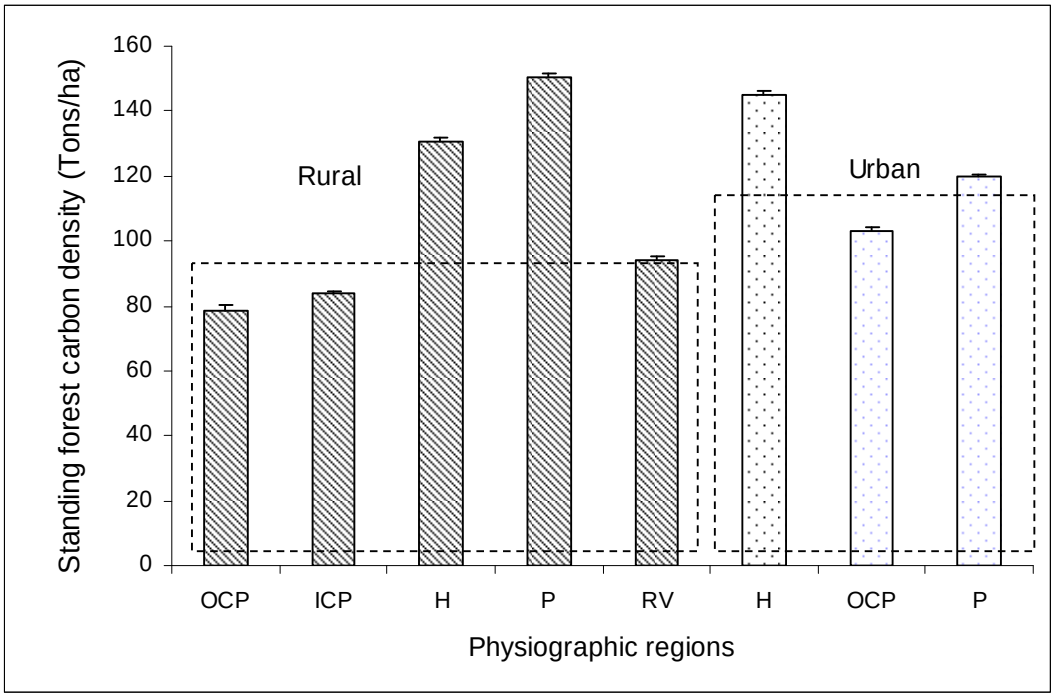

Figure 5. Average standing forest biomass carbon density by physiographic regions and Rural/Urban/ division (the bar represents upper error limit of carbon content; the lower error limit is the same with the upper error limit). Note that the FIA did not have any plot data within the urbanized zone of the Ridge & Valley or the Inner Coastal Plain physiographic provinces and thus no carbon density estimates were available for urban forests.

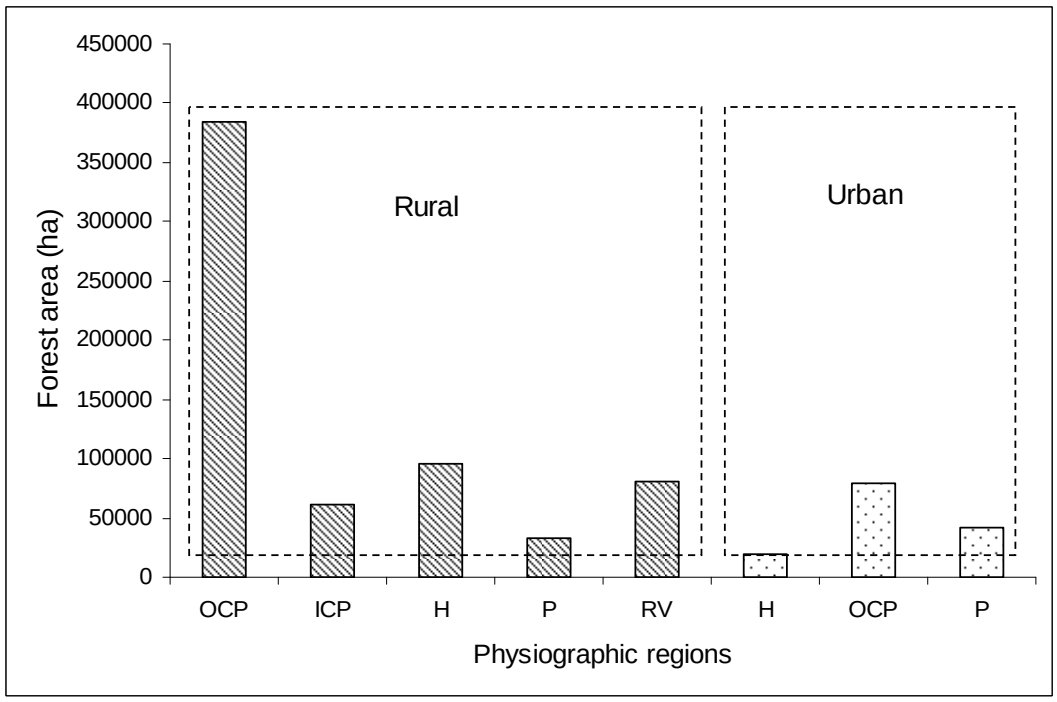

Figure 6. Forest area in each physiographic region and by Rural/Urban division.

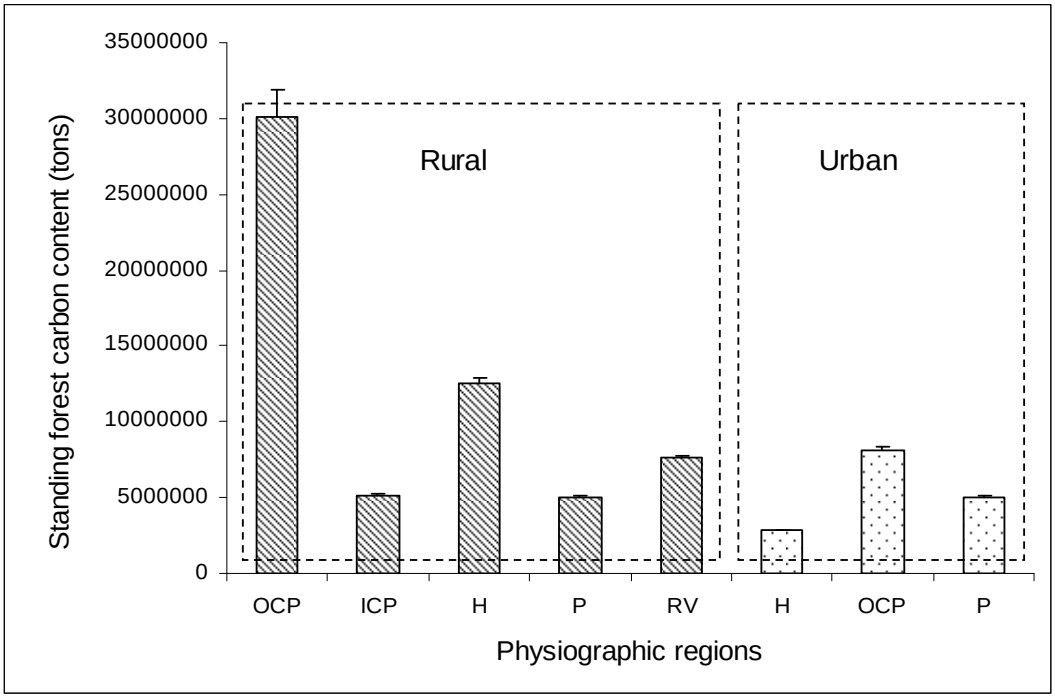

Figure 7. Total standing forest biomass carbon content as inferred from FIA data by physiographic regions and grouped by Rural/Urban division. Note: the error bar represents the sampling error. The standard error bars for P and Urban H were too small to be displayed.

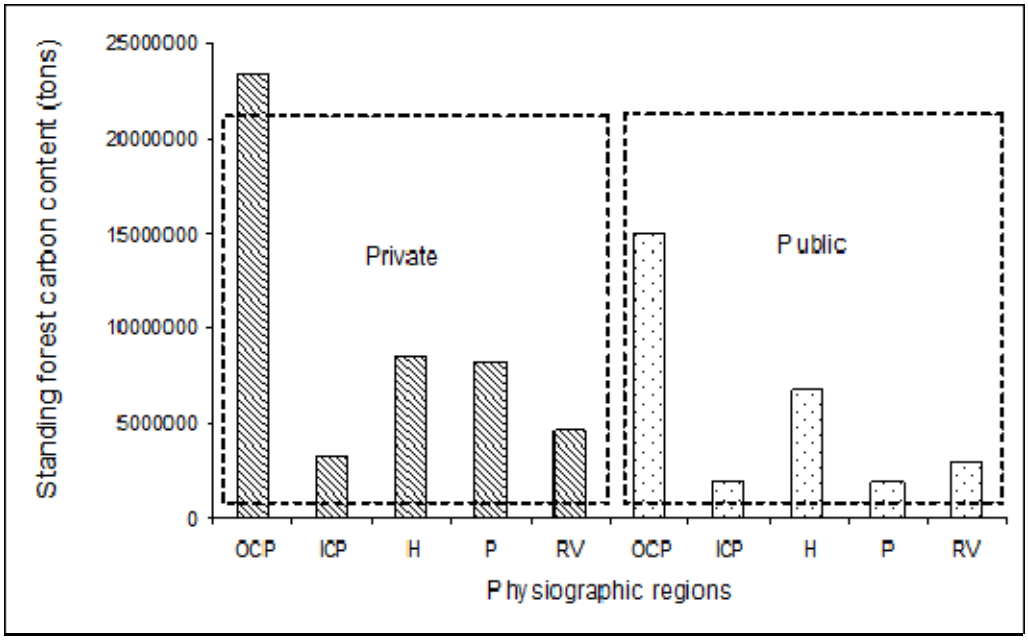

Figure 8. Standing forest biomass carbon contents summarized by private vs. public land.

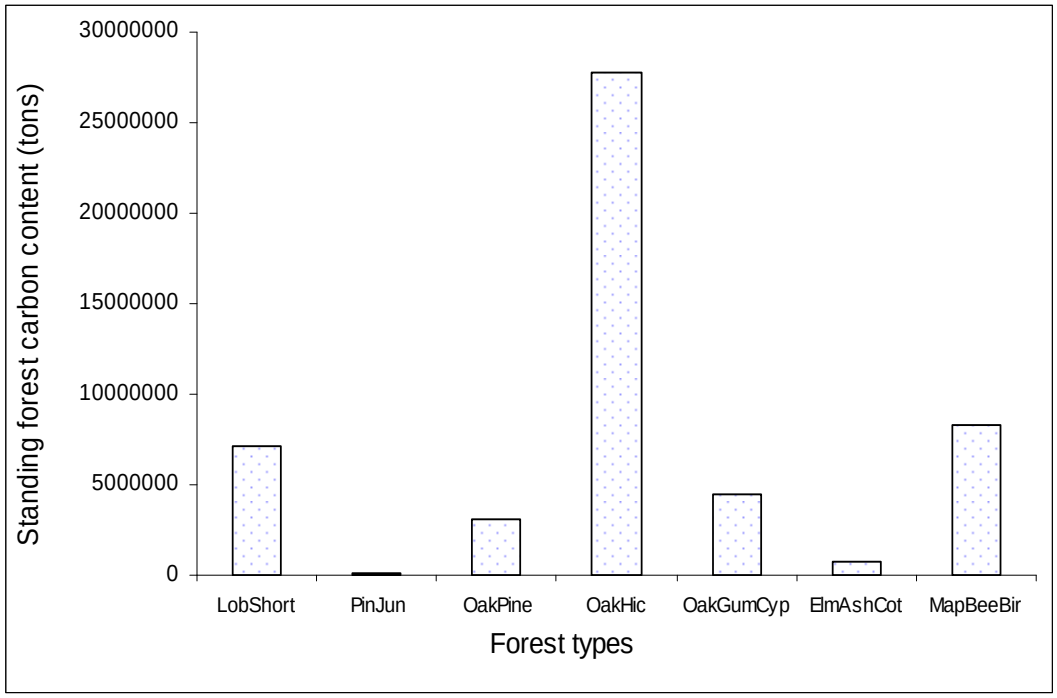

Figure 9. Standing forest biomass carbon contents summarized by USDA forest types. (Lobshort: Loblolly / shortleaf pine group, in NJ locally referred to as pitch/shortleaf pine or PtichShort; Pinjun: Pinyon / juniper group, in NJ referred to as VirginiaRedCedar; OakPine: Oak / pine group; OakHic: Oak / hickory group; OakgumCyp: Oak / gum / cypress group, in NJ locally referred to as CedarMapleGum; ElmAshCot: Elm / ash / cottonwood group, in NJ locally referred to as ElmAshPoplar; MapBeeBir: Maple / beech / birch group).

2.2. Shrubs

Based on the lookup table calculation, the carbon stock stored in shrubs is estimated to be approximately 1,575,043 tons with a range between 1,544,960 and 1,605,126 tons based on FIA data sampling error standard. The ratio of shrub to tree biomass in a stand as calculated from the FIA lookup table dataset was 1.4%. This NJ-wide shrub/tree biomass ratio is somewhat below that calculated for the NJ Pinelands based on US Forest Service plot data where shrub/tree biomass ratios ranged from 2.3% ~ 11.9% (Table 4). However, this discrepancy is not unexpected in that the open canopy of the Pinelands pine-dominated forests often have a dense shrub layer (Robichaud and Buell, 1983).

Table 4. Structural characteristics of three 1 km^2 intensive study plots in the Pinelands of New Jersey (Skowronski, et al., 2007).

	Oak/Pine	Pine/Oak	Pine/Scrub Oak
Understory			
Scrub Oak biomass (ton ha^{-1})	0.2 ± 0.5	2.2 ± 2.1	0.7 ± 0.7
Other Shrub biomass (ton ha^{-1})	1.7 ± 1.1	1.1 ± 1.0	3.2 ± 0.8
Total shrub biomass (ton ha^{-1})	1.9 ± 1.1	3.3 ± 2.1	3.9 ± 1.3
Shrub/tree biomass ratio (%)	2.3%	6.9%	11.9%

2.3 Down dead wood (DDW)

Based on our regression model simulation generated from the 20 FIA plots, we estimate the DDW in New Jersey's forest land to be 15,116,795 tons of carbon, with a range between 13,886,504 and 16,347,087 tons.

DDW distribution had strong spatial pattern as characterized as a decreasing gradient from the high end in Outer Coastal Plain and Highland regions to the low end in Inner Coastal Plain region (Fig 10). In rural areas, Outer Coastal Plains forest had the highest DDW carbon density, followed by Inner Coastal Plains forest (Fig. 11). In urban areas, Outer Coastal Plains forest had the highest DDW carbon density, and Highlands had the second highest DDW carbon density. Urban forest had an estimated 8 tons/ha DDW carbon density, while rural forest had a 9 tons/ha DDW carbon density. Urban forest had an estimated total 4,034,191 tons of carbon stored as DDW and rural forest had a total 11,082,604 tons of carbon stored as DDW (Fig. 12).

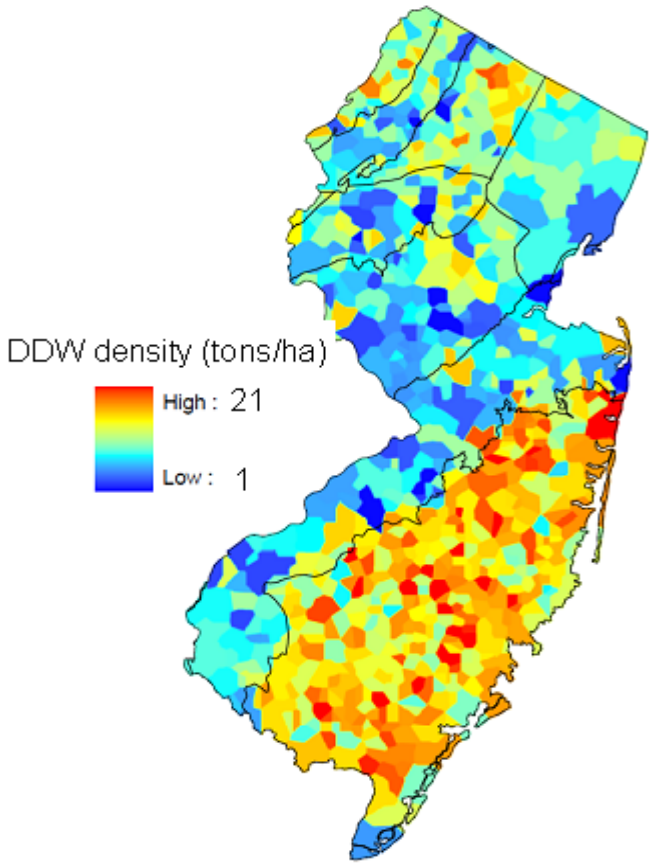

Figure 10. Down dead wood carbon density distribution in New Jersey.

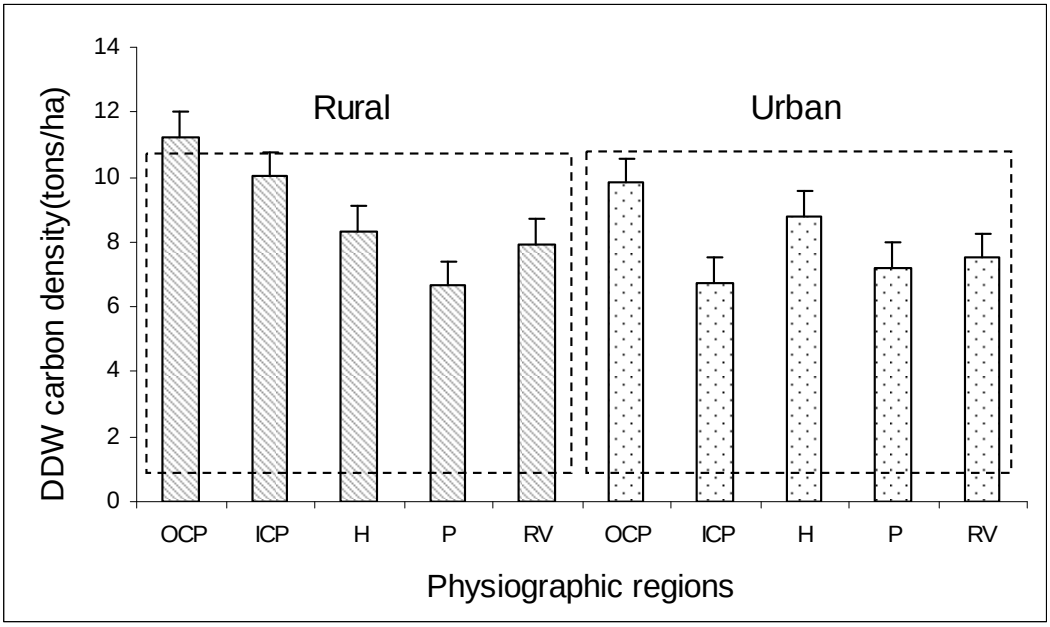

Figure 11. Down dead wood carbon density for each physiographic region grouped by Rural/Urban division.

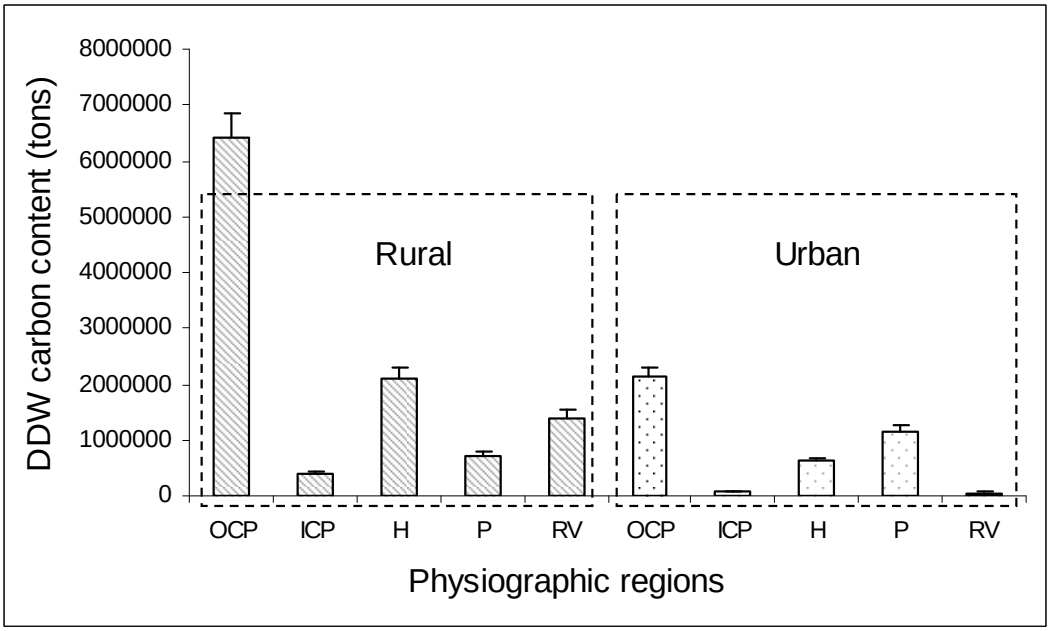

Figure 12. Down dead wood carbon content for each physiographic region grouped by Rural/Urban division.

2.4 Soil Carbon

The forest soil organic carbon for a 100cm depth of soil is estimated to be approximately 72,971,138 tons (Table 5) with an error range of between 31,589,385 and 123,108,236 tons. The large range between the low and high estimate reflects the variability between the minimum and maximum attributes for individual soil types in the SSURGO database. Soil organic carbon had a

high variation among physiographic regions and Rural/Urban divisions. Note that the highest soil carbon densities are found in the organic peat soils of coastal tidal wetland areas of the Outer and Inner Coastal Plains regions, as well as freshwater wetlands of the Piedmont and Highlands (Fig. 13), and not included in our estimates of forest soil carbon stocks.

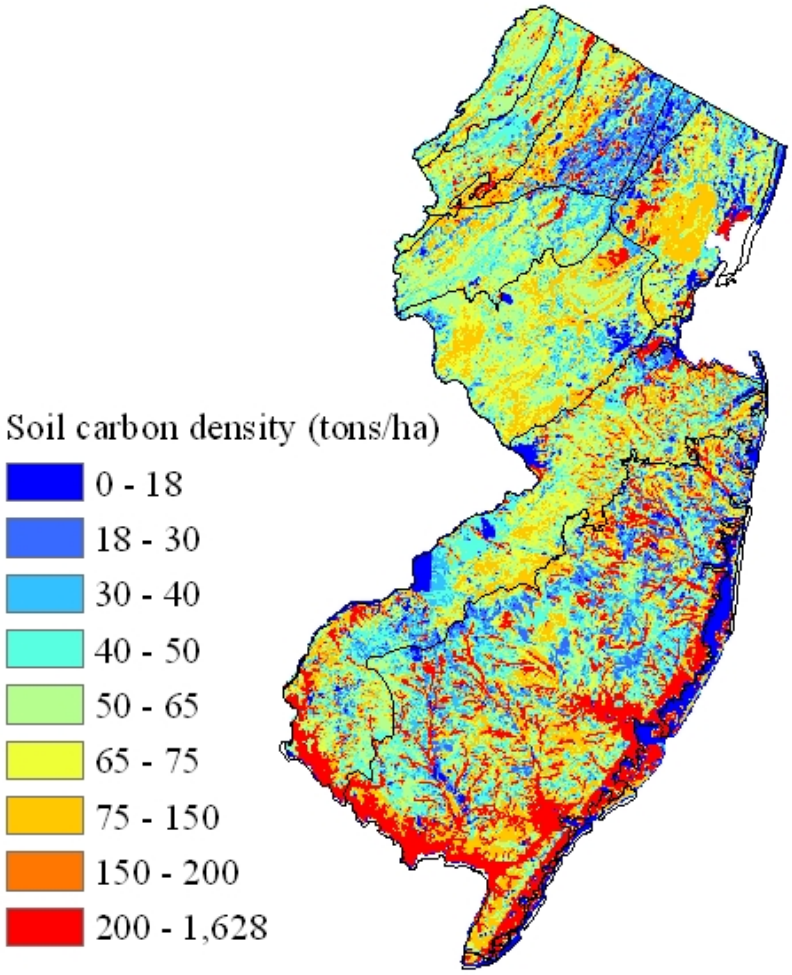

Figure 13. Soil carbon density distribution in New Jersey

The rural area of the Inner Coastal Plain had the highest soil organic carbon density (tons/ha), followed by rural Outer Coastal Plains (Fig. 14). Other physiographic regions in the rural area had similar soil organic carbon density. In the urbanized region a similar pattern was found with the Inner Coastal Plain having the highest soil carbon density, followed by Outer Coastal Plain physiographic region. Overall, the rural area had higher soil carbon density than the urban area.

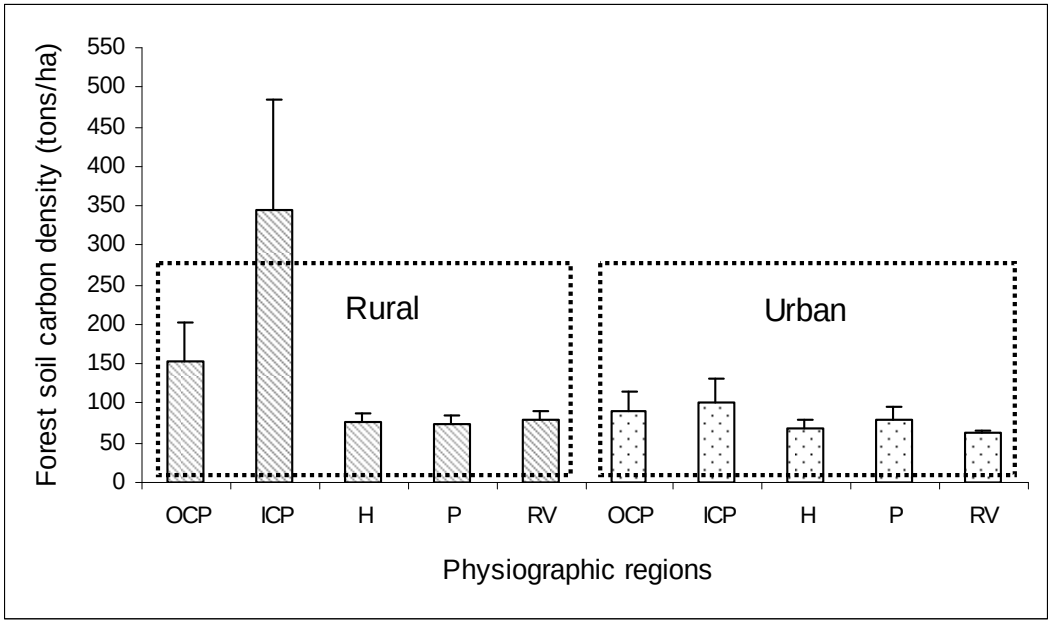

Figure 14. Forest soil carbon density for each physiographic region grouped by Rural/Urban division in New Jersey.

The urban area had an estimated total of 15,360,500 tons of soil carbon, while the rural soil had a total of 57,610,638 tons of carbon (Fig. 15). Outer Coastal Plains in rural region had the highest soil carbon content, followed by Inner Coastal Plain in rural region. Outer Coastal Plains in urban region had the third highest soil organic carbon content, which implies that urban area in New Jersey is a significant component in storing carbon. Piedmont in urban region contributed as the fourth biggest soil carbon pool in New Jersey. These four carbon pools combined account for 82.4% of soil organic carbon in New Jersey.

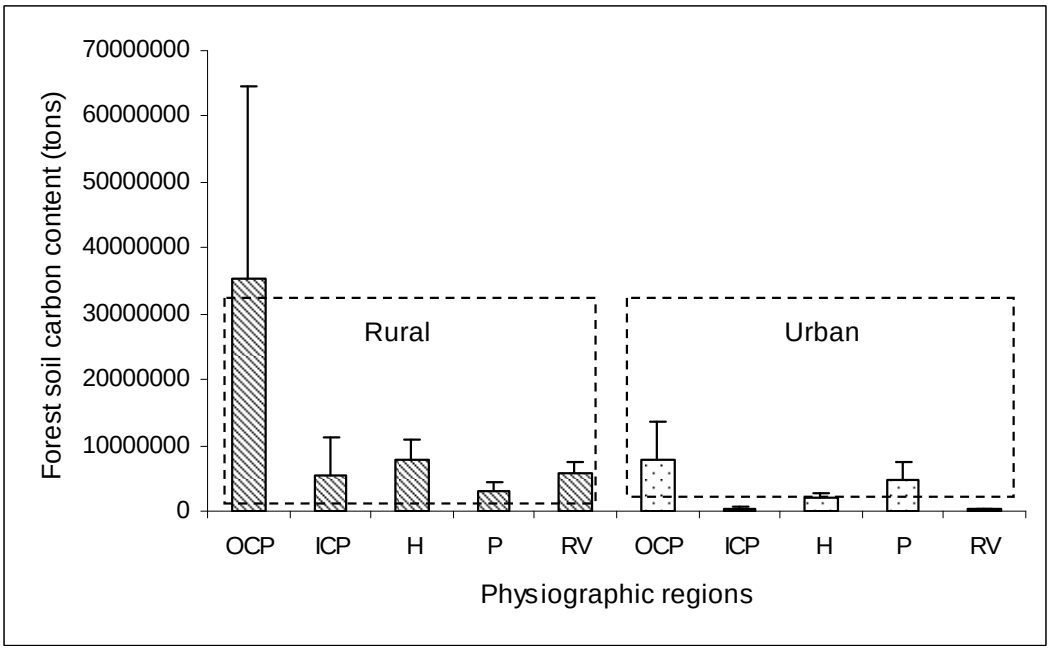

Figure 15. Forest soil carbon content for each physiographic region grouped by Rural/Urban division.

2.5. Root carbon content

The root zone had an estimated total 7,342,653 tons of carbon and with a range between 7,202,408 and 7,482,898. Rural Outer Coastal Plains had the largest root carbon content, followed by rural Highlands. The urban Highlands had the lowest root carbon (Fig. 16).

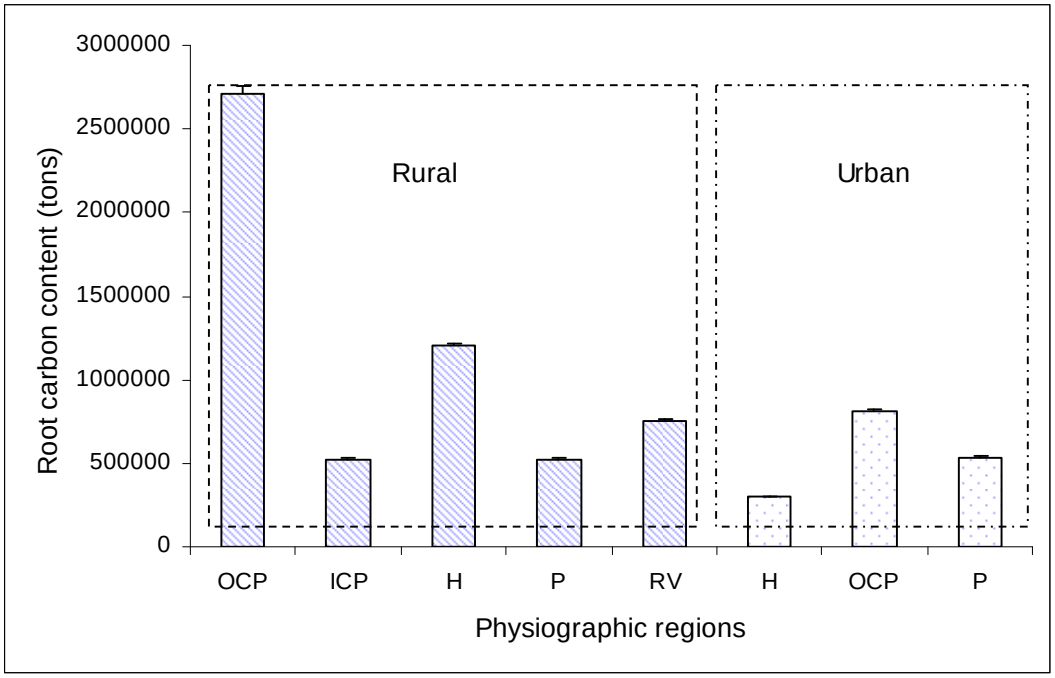

Figure 16. Root biomass carbon content for each physiographic region grouped by Rural/Urban division.

2.7. Accumulated live biomass carbon stock and annual carbon flux

The IntCarb model simulates the growth of a forest on land that has been cleared and allowed to regenerate back to forest. The model 'grows' the forest from Time 0 through maturity (Time 300) and tracks the carbon accumulation over the 300 year modeling period. In the Outer and Inner Coastal Plain, forest carbon densities (ton C/ha) are estimated to reach their peak with a value of 116 ton C/ha at year 69 and then decreases (Fig. 17). The Ridge and Valley and Highlands forests are estimated to reach their maximum carbon density at year 117 with a value of 150 ton C/ha. Piedmont forests are estimated to reach its maximum carbon density at year 137 with a value of 143 ton C/ha. After their peak growth stages, forest stands tend to mature and thin in tree density thereby declining in overall carbon stock. Based on the FIA data, the average stand age for Ridge and Valley, Highlands, Piedmont, Outer Coastal Plain, and Inner Coastal Plain, and Highlands were 75, 87, 54, 65, and 58 years, respectively. Live aboveground biomass carbon density (tons C/ha) as calculated from FIA data was plotted against the IntCarb simulation estimates with average stand age as X-axis value and carbon density as Y-axis value (Fig. 17). The IntCarb simulation results suggests that, based on the average age of forest stands that the Inner and Outer coastal plain forests, are close to the peak forest carbon density. The Ridge and Valley, Highlands and Piedmont forest are still upwards of 50 to 75 years away from

peak growth and based on the model simulations, we can expect these forests to continue to accumulate carbon for the next several decades.

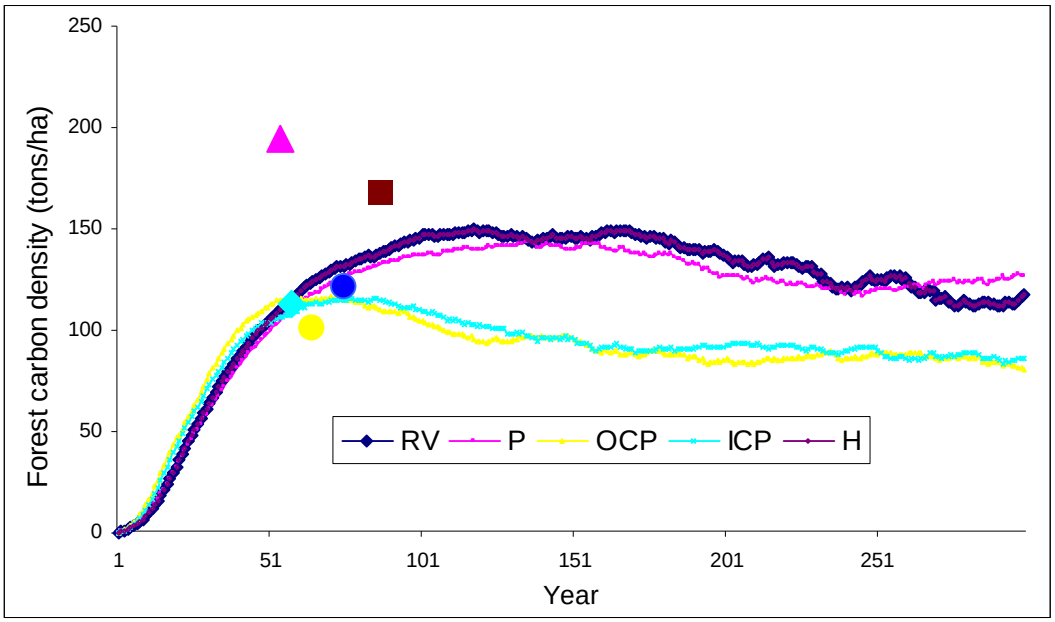

Figure 17. Forest live biomass carbon density (including above-ground stem, leaf, and branch) by stand age for each physiographic region in New Jersey. The dot, triangle and cubic represent validation result from FIA data for the five physiographic regions. The symbols' color are the same as their corresponding trajectory color.

Live aboveground biomass carbon density (tons C/ha) as calculated from FIA data were compared against the IntCarb simulation estimates (Table 5). The IntCarb simulation outcome matched the FIA measurement reasonably well in the Ridge and Valley, Highlands, Outer Coastal Plain, and Inner Coastal Plain regions (i.e. within ±4 to 18%) (Table 5). For the Piedmont region, the IntCarb model results were only 54% of the FIA calculated estimate (Table 5). It is unclear why the model underestimated the live biomass carbon density in this physiographic region (or conversely why the FIA estimates where higher).

Table 5.Comparions between model biomass results and FIA calculated results

	Ridge & V	Piedmont	Outer Coastal Plain	Inner Coastal Plain	Highlands
Model total	147.3	118.1	128.4	121.6	155.1
Model belowground	16.3	13.1	14.4	13.6	17.1
Model aboveground	131	105	114	108	138
FIA aboveground	121	194	101	113	168
Model/FIA aboveground ratio	1.08	0.54	1.13	0.96	0.82

Note: the model total includes only aboveground and belowground biomass; the model belowground includes only belowground root biomass

Live biomass carbon stock followed an identical trend with carbon density (Fig.18). Each physiographic region area multiplied by the modeled carbon density was used to estimate the total live biomass stock in each physiographic region. With its extensive area, the Outer Coastal Plain physiographic region was estimated to have the largest carbon stock (tons), followed by Highlands, the Ridge and Valley, and the Inner Coastal Plains. The live biomass stock was the lowest in the Piedmont region. The maximum live biomass stock capacity for the Outer Coastal Plains region is 50,454,102 tons, 16,169,963 tons for the Highlands region, 13,616,500 tons for the Ridge and Valley region, 8,006,792 tons for the Inner Coastal Plain region and 5,382,981 tons for the Piedmont region.

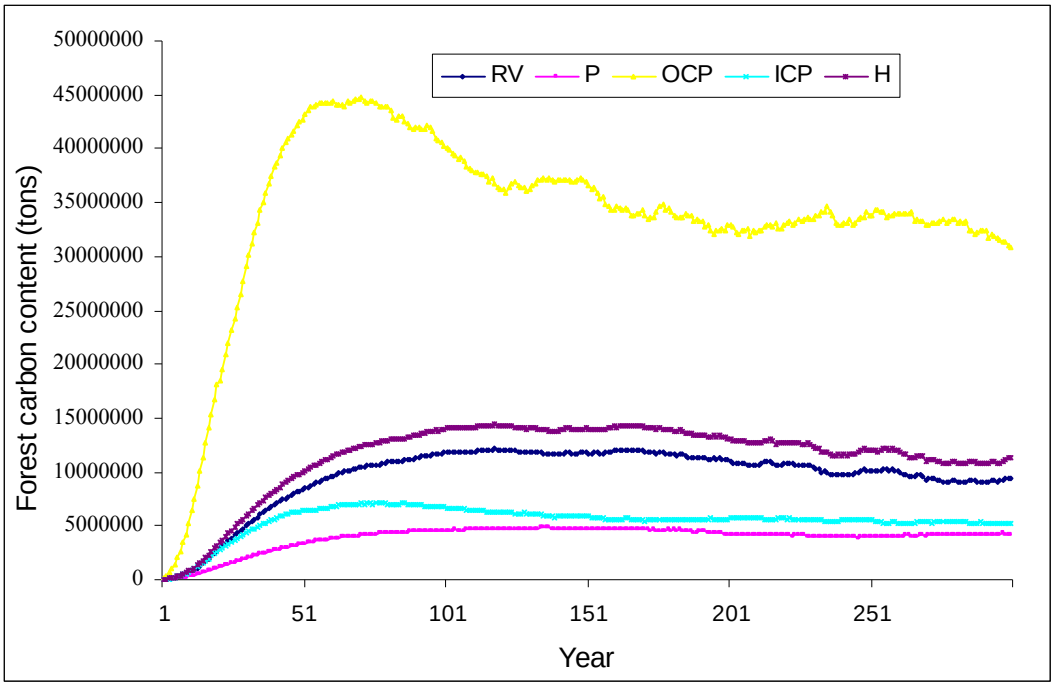

Figure 18. Accumulated forest live aboveground biomass carbon content (including stem, leaf, branch, and roots) dynamics by stand age for each physiographic region in New Jersey.

The IntCarb model was used to estimate the annual carbon flux. Positive annual flux values represent carbon sequestration (storage in the forest) and negative flux values represent carbon emission to the atmosphere. Over longer time periods, as long as the cumulative positive flux is greater than the negative flux, then the forest will store and accumulate carbon (i.e., the forest will serve as a sink and carbon stock increases). In Ridge and Valley, Highlands, and Piedmont, forests aged between zero and 80 acted as a carbon sink (i.e. sequestered more than was emitted) (Fig. 19). Around year 30, forests in the above three physiographic regions reached their maximum carbon sink capacity with an annual sequestration of approximately 2.5 tons/ha. Between year 80 and 200, Ridge and Valley, Piedmont and Highland forests, the carbon flux went negative with more carbon being emitted than stored and thus acting as a carbon source to

the atmosphere. After year 200, these regions' forests carbon stock (i.e., total carbon stored) reached a steady status. In the Inner and Outer Coastal Plains physiographic regions, forests acted as a carbon sink at ages younger than 50 years. Their carbon sink capacity expanded between year zero and 25 and then the sink capacity shrank between year 25 and 50. Between year 80 and 130, the coastal plains forests acted as a carbon source since many trees reached their longevity and they released a significant amount of carbon as they died and decomposed. Due to its large area, the Outer Coastal Plain was estimated to have the largest flux (sink) at over 1,500,000 tons as well as the largest oscillations in flux in later years.

When forests in each physiographic region reach a steady status, the largest live biomass carbon flux is estimated to be 550,961 tons for the Outer Coastal Plains region, 205,609 tons for the Highlands region, 167,729 tons for the Ridge and Valley region, 83,613 tons for the Inner Coastal Plains, and 61,030 tons for the Piedmont region, respectively (Fig. 20). The carbon flux for the entire state is estimated to be 1,068,942 tons. The flux is estimated to reach a maximum of 1,089,466 and a minimum of 1,048,418 tons, respectively.

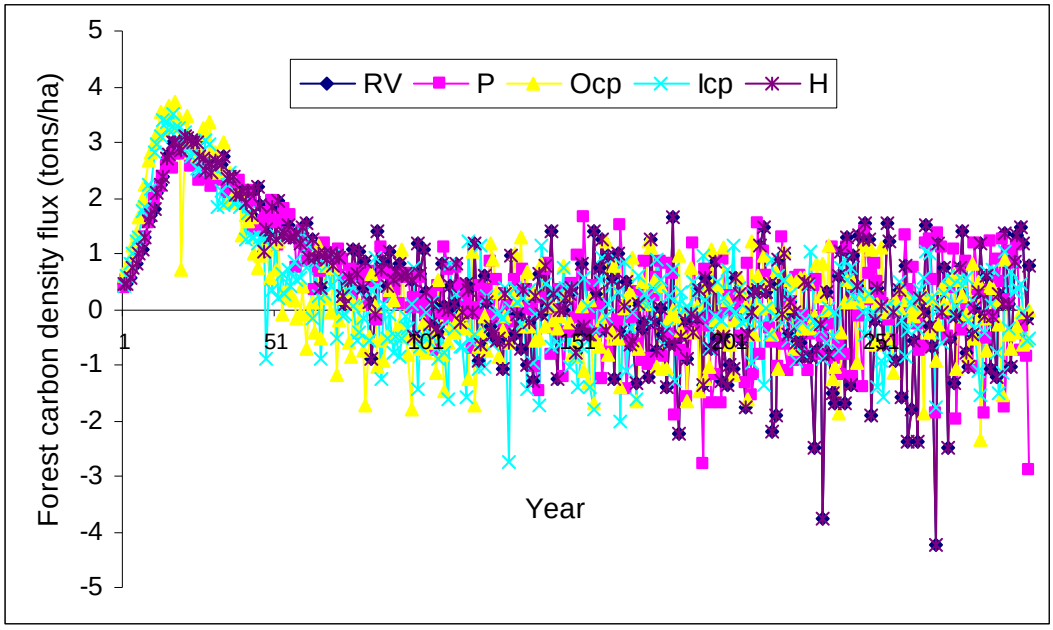

Figure 19. Flux of forest live biomass carbon density (including stem, leaf, branch and roots) for the five physiographic regions in New Jersey. Positive flux values represent carbon sequestration and negative flux values represent carbon emission.

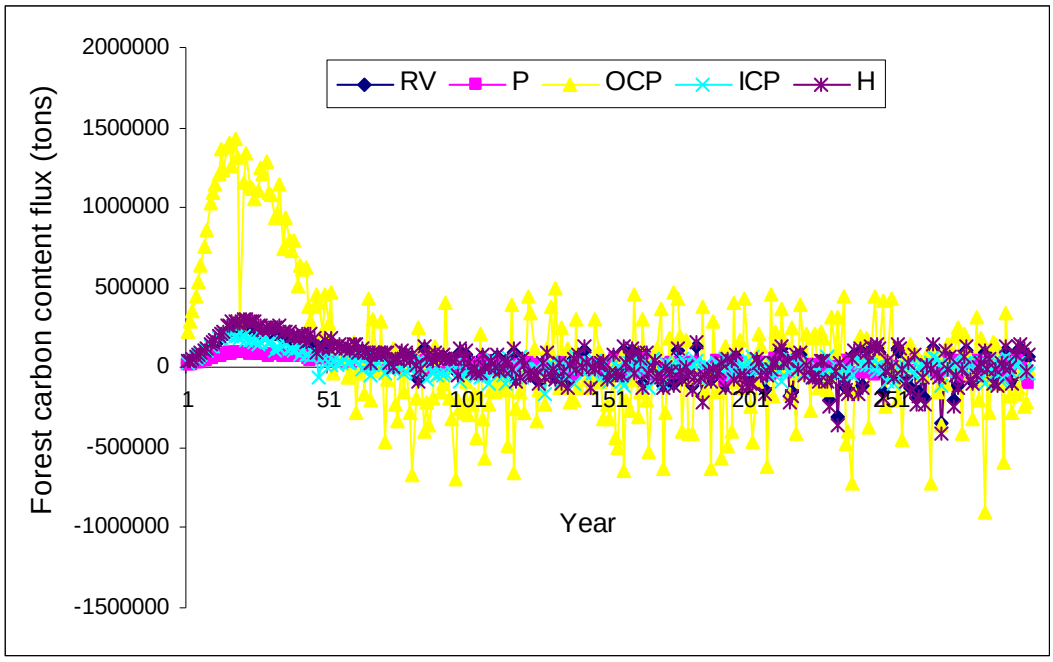

Figure 20. Flux of forest live biomass carbon density (including stem, leaf, branch and roots) for the five physiographic regions in New Jersey

2.8 Soil carbon flux

The IntCarb model simulations suggest that in the first two decades of forest regeneration, forest soils act as a carbon source (i.e., soil carbon density decreases) as organic matter in soil is respired and releases carbon back to the atmosphere (Fig. 21). This situation reverses and soils then start to sequester carbon and become carbon sinks. The Ridge and Valley, Piedmont, Outer Coastal Plain, Inner Coastal Plain, and Highlands regions acted as soil carbon sinks during the period between 25 and 139, 25 and 141, 25 and 90, 25 and 95, and 25 and 139 years, respectively. Ridge and Valley, Piedmont, Outer Coastal Plain, Inner Coastal Plain, and Highlands soils reached their maximum carbon sink capacity in year 44, 65, 46, 39, and 44. Due to the larger size of the Outer Coastal Plain region, this region represents the largest store of soil carbon (Fig. 22). After reaching maturity between the years of 100 to 150, belowground soils in the various physiographic regions tended to oscillate between a positive and negative annual flux (Fig. 23). The maximum carbon sequestration across the modeling time period was 295,168 tons C for the Outer Coastal Plain region, 43,389 tons for the Inner Coastal Plain region, 21,644 tons for the Piedmont region, 66,362 tons for the Highlands region, and 56,545 tons for the Ridge and Valley region (Figure 24). When forests in each region reach a steady state condition, the belowground soil carbon flux oscillates around zero (Fig. 24).

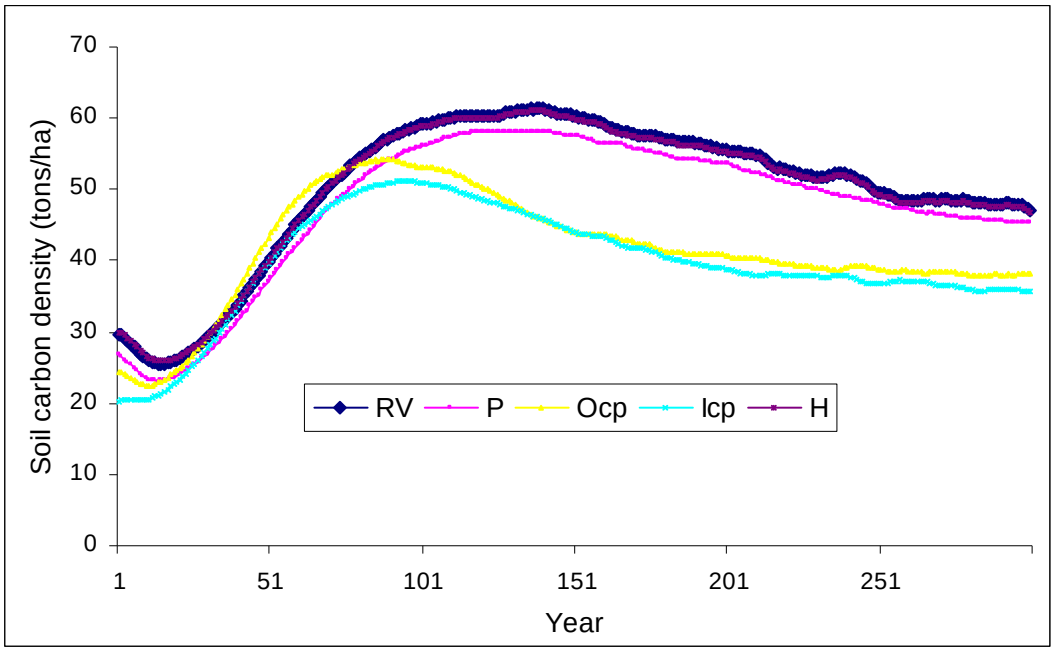

Figure 21. Soil carbon density dynamics by stand age for each physiographic region in New Jersey

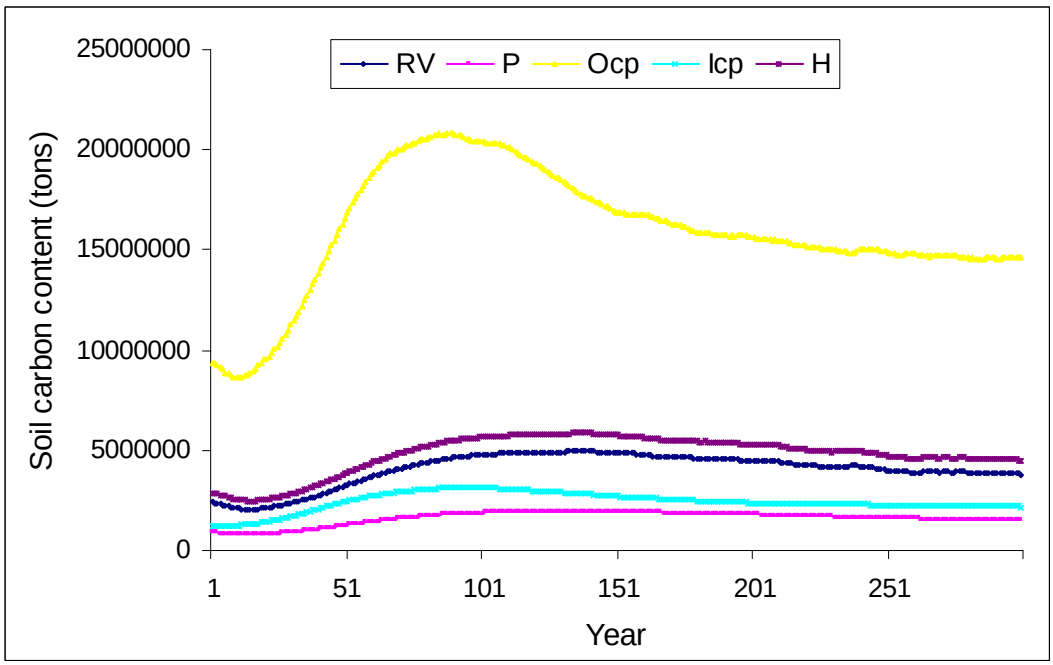

Figure 22. Accumulated soil carbon content for each physiographic region in New Jersey.

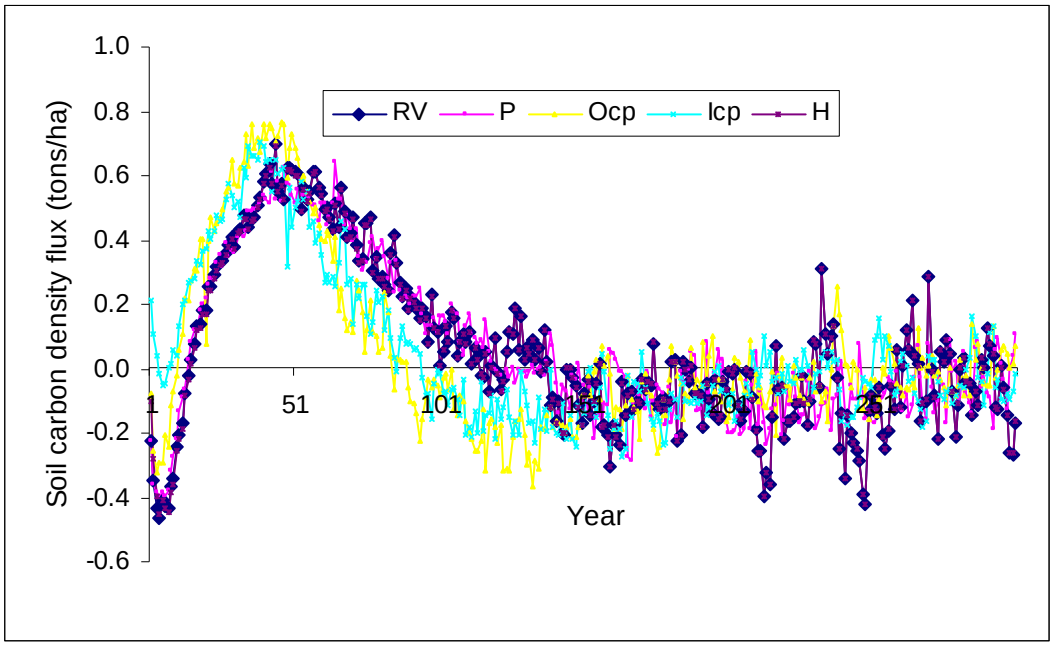

Figure 23. Soil carbon density flux for the five physiographic regions.

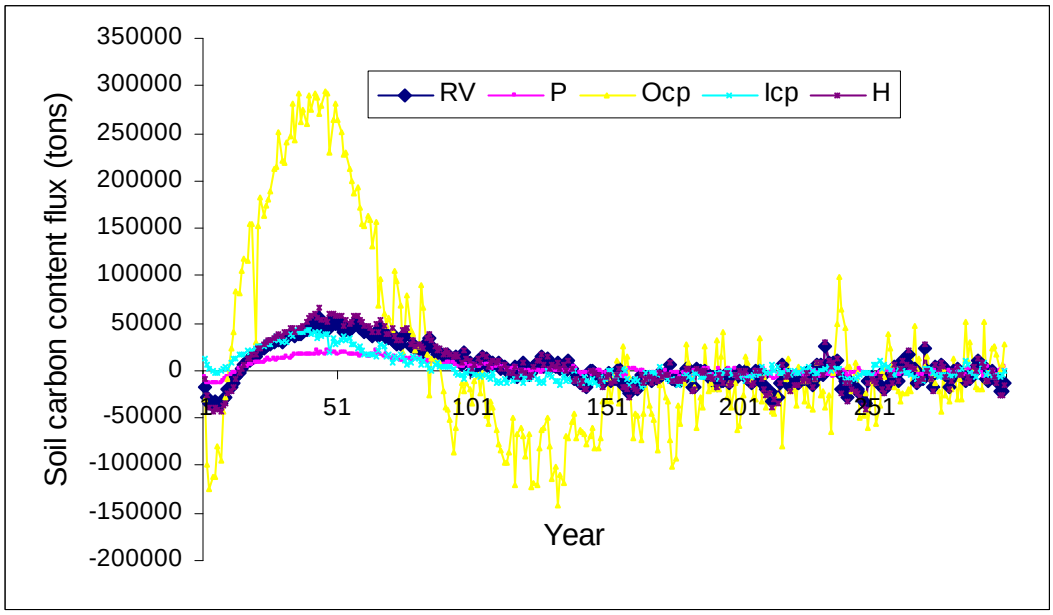

Figure 24. Soil carbon content flux for the five physiographic regions.

2.9 Net Primary Production

Net primary production (NPP) is a measure of the net amount of biomass (or carbon equivalent) produced by plants in a forest system after deducting plant respiration. The results for the IntCarb model simulations were validated against several other modeling studies for the Outer Coastal plain ecoregion (Fig. 25). Net Primary Productivity (NPP) for several typical Pinelands forest study sites have been estimated by a locally parameterized ecosystem model (WxBGC) and calculated from FIA data (Miao, et al., in review; Pan, 2006). The WxBGC model

was run for the three locations within Pinelands: an oak/pine forest at Silas Little Experimental forest; a pine/oak forest at Fort Dix; and, a pine/scrub oak forest at Cedar Bridge. These 3 Pinelands study sites are broadly representative of the Outer Coastal Plains physiographic region. The NPP was estimated to be 499.7 gC $m^{-2}yr^{-1}$for Oak/Pine forest, 452 gC $m^{-2}yr^{-1}$ for Pine/Oak, and 426.6 $m^{-2}yr^{-1}$ for Pine/Scrub oak, respectively. The average for the three forest types was 448 $m^{-2}yr^{-1}$. The Pinelands-wide estimate calculated by Pan (2006) using FIA data was 448 $m^{-2}yr^{-1}$. The IntCarb model predicted that NPP for Outer Coastal Plains region to be approximately 486 $m^{-2}yr^{-1}$ which compares closely with both the WxBGC model prediction and FIA calculation (i.e. within 8%).

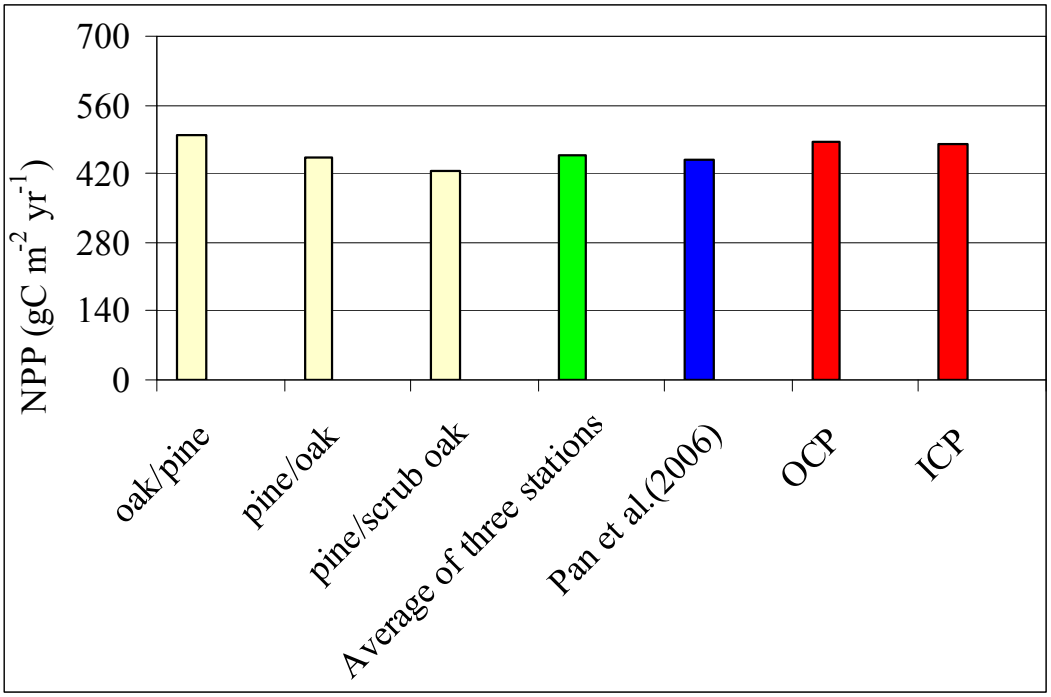

Figure 25. Comparison of NPP estimated by WxBGC model (yellow columns) and FIA (Pan et al., 2006) (blue column) with the IntCarb-estimated NPP (red column) for typical Pinelands forest study sites as well as Outer and Inner Coastal Plains regional estimates, New Jersey.

2.10. Carbon credit for New Jersey forest land

To estimate carbon credits for New Jersey forest lands, we used the IntCarb model to simulate a typical tract of farmland that is regenerated into forest land to estimate the amount of carbon sequestered over the modeled 300 year time horizon. The product integrated both belowground and aboveground results. A typical New Jersey forest is predicted to be a carbon sink for the first 75 years (Fig 26). By year 75, accumulated carbon density in New Jersey forest is approximately 150 tons/ha. After the peak growth stage of around 75 years, the amount of carbon stored in the forest stand starts to decline as the stand matures and thins in tree density. At Year 325, the carbon stock is less than 75% of that at age 75. After year 400, the IntCarb model suggests that an average, New Jersey forest will maintain a relative equilibrium where the amount of carbon fixed and stored annually stored is equal to released carbon with total accumulated carbon stock of approximately 120 tons C/ha maintained indefinitely.

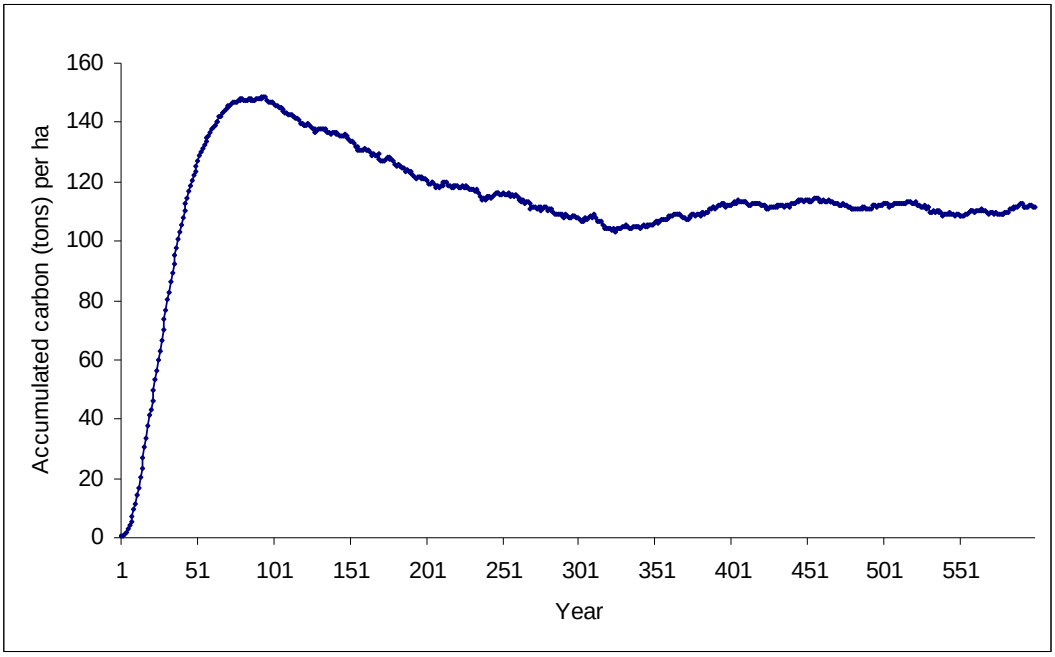

Figure 26. Accumulated carbon density for a typical tract of New Jersey forest land.

2.11 Total forest carbon stock

The total carbon storage in New Jersey's forests was summed across the various components to calculate a total estimate of approximately 172,846,595 tons of carbon, among which standing trees accounted for 44%, soil accounted for 42%, shrubs contributed 0.1%, down dead wood contributed 9%, and roots contributed another 4% (Table 6, Fig 27). The upper and lower limits of total carbon storage were 128,615,661 and 225,832,875 tons, respectively.

Table 6. Overall results: Organic Carbon storage for each forest system component (tons). The values within the brackets are carbon storage ranges for each component.

Parts	Data sources	Contents (tons)
Standing forest biomass	FIA	75,840,966 (74,392,404-77,289,528)
Shrub	Lookup table	1,575,043 (1,544,960-1,605,126)
DDW and forest floor	FIA DDW inventory data and model calculation	15,116,795 (13,886,504-16,347,087)
Soil organic carbon	SSURGO	72,971,138 (31,589,385-123,108,236)
Root biomass carbon		7,342,653 (7,202,408-7,482,898)
Total		172,846,595 (128,615,661-225,832,875)

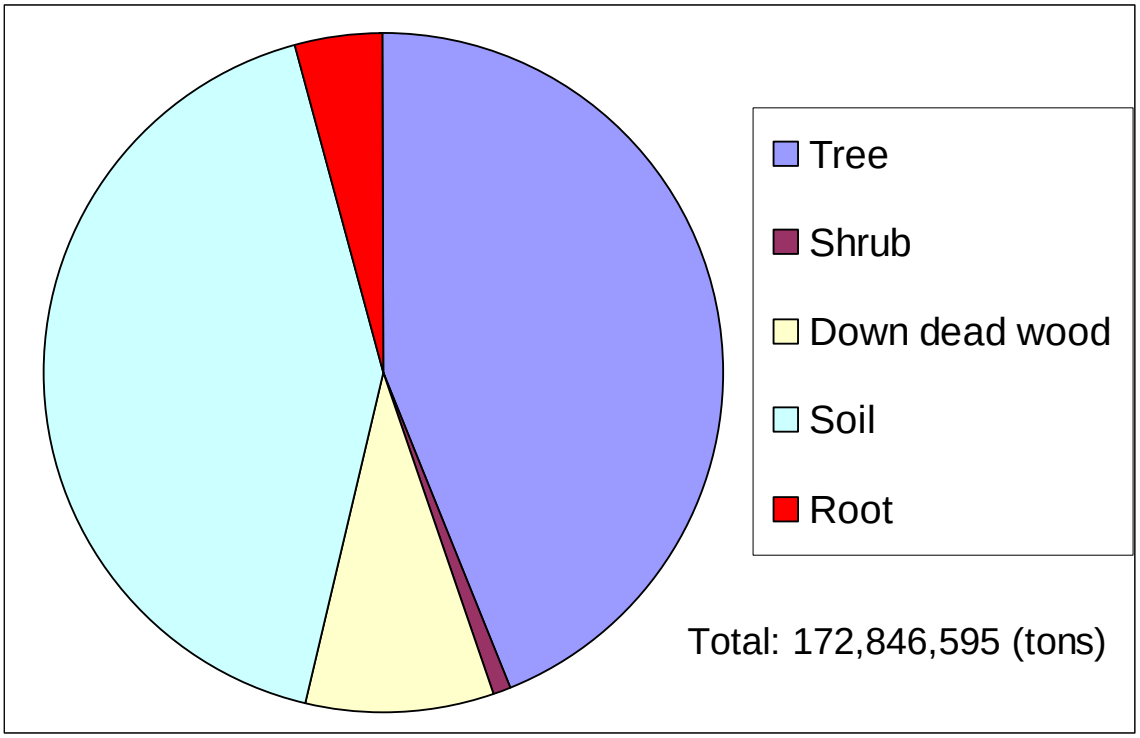

Figure 27. Overall results: Organic Carbon storage for each forest ecosystem component (tons)

Discussion and Conclusions

Among the many ecosystem services that New Jersey forests provide, their role in sequestering carbon is receiving greater attention and appreciation (Costanza, et al., 2006; NJDEP, 2007). This study represents a "first cut" at compiling existing forest inventory and modeling information to estimate the carbon stock and annual flux in New Jersey's forests. We estimate the total carbon stock in above-ground biomass to be approximately 92,532,804 tons. Dividing this amount by the 996,820 hectares of forest land (as of 2005, Table 1), provides an estimate of approximately 93 metric tons/ha on average. This closely compares with the 95 metric tons/ha value estimated by the NJDEP in the New Jersey Greenhouse Gas Inventory (2008; Appendix H). We estimate the total carbon stock stored in New Jersey's forest land is approximately 172,846,595 tons (with an upper and lower range of 128,615,661 and 225,832,875 tons). This estimate includes organic carbon stored in live and dead trees, shrub, down dead wood, root, and soil. Dividing this amount by the 996,820 hectares of forest land (as of 2005, Table 1), provides an estimate of approximately 173 metric tons/ha on average.

Increased standing aboveground forest carbon density caused by a growing forest, as well as increased forest coverage, led to an overall increase in forest aboveground biomass carbon stock between 1987 to 2005 from approximately 40,804,634 tons (range 39,919,173 and 41,690,095) in 1987, and 75,840,966 tons (range between 74,392,404 and 77,289,528) in 2005 (Fig. 15). This represents an approximately 86% increase between 1987 and 2005. While a confidence interval was estimated, further research work is needed to more adequately characterize the uncertainty in the carbon stock estimates. Taken on an annual basis, New Jersey forests increased carbon storage (in aboveground woody tissues) from a rate of approximately

1,711,440 tons/yr between 1987 and 1999 to approximately 2,416,560 tons/yr between 1999 and 2005.

This study provides a spatially explicit picture of carbon stock by presenting results by physiographic region. In addition, estimates were also undertaken (where feasible and appropriate) by other categorizations: forest type, rural vs. urban land use, private vs. public ownership. The IntCarb modeling of carbon flux vs. sequestration was undertaken by physiographic region as the underlying physical environment (i.e., soil and climate) are major driving factors for the model simulations. Each physiographic region also has a distinctive tree species composition. For example, pitch pine dominates the forests in the Outer Coastal Plain, while mixed oak species dominate in the Highlands and Ridge and Valley regions. Though the overall carbon density (tons C / ha) is generally lower, due to its large area of forest land, the Outer Coastal Plain plays an outsize role in that state's overall forest carbon dynamics.

The IntCarb ecosystem model suggests that the Outer and Inner Coastal Plain forest reach a peak forest carbon density of 116 ton C/ha around year 69 and then decrease (Fig. 17). The Ridge and Valley, Highlands and Piedmont forests are estimated to reach their maximum carbon density between year 117 and 143 with an estimated carbon density of over 140 ton C/ha. The simulation results suggests that, based on the average age of forest stands (as determined by the FIA data), that the Inner and Outer coastal plain forests are close to the peak forest carbon density. The Ridge and Valley, Highlands and Piedmont forest are still upwards of 50 to 75 years away from maximum carbon storage and based on the model simulations, we can expect these forests to continue to increase the rate at which they accumulate carbon for the next several decades. Once forests reach maturity, the model suggests that the amount of carbon stored (i.e. the carbon stock) in above-ground standing biomass tends to decline. However the above-, below-ground biomass and soil organic matter in these forests continue to sequester carbon for an additional 25 to 50 years before reaching a steady state.

The ongoing accumulation of carbon in individual forests is being somewhat counteracted by the accelerating loss of forest land. Urbanization has continued to expand impacting over 3,000 hectares of forest land per year between 1995 and 2007 (Hasse and Lathrop, 2008, 2010). While in many cases, these forests were razed and converted to impervious surface and lawns, in other cases tree cover remains at some lower level. Our study indicates that the standing forest carbon density (tons per ha) is sometimes higher in urban areas than in rural areas. We are unsure as whether this is real ecological pattern or an artifact of the spatial data aggregation. The sprawling pattern of urbanization in New Jersey confounds the classification of urban and rural areas. Urban forests include extensive areas of low density development in both suburban/exurban settings as well as parklands that contain extensive amounts of forest land. Regardless, with the large amount of forest land classified as urban in New Jersey, these urban forests play a significant role in statewide carbon sequestration.

While the above-ground biomass is an important pool of stored organic carbon, soil represents the second largest stock of soil carbon. Globally, belowground carbon is estimated to be twice that of the aboveground carbon pool. Part of this global difference is attributed to large area of grassland and agriculture where the aboveground biomass is limited (as compared to forests) (Ruesch and Gibbs, 2008). As way of comparison, New Jersey land is covered by less than 30% of upland forest. Other land uses such as emergent wetland, including both freshwater and estuarine, represent a large belowground carbon pool due to the significant proportion of land cover in New Jersey The upland forest, cultivated/grassland, unconsolidated shore (mud and sand flats) and wetlands covered 28%, 17%, 1%, and 19% of New Jersey, respectively based on

2001 land use/land cover map (Hasse & Lathrop, 2008). The aboveground biomass for emergent wetlands was not estimated as part of this study. Average soil carbon density of agricultural land is 70 tons/ha, which is slightly higher than that of forest land (66 tons/ha), whereas soil carbon density of unconsolidated shore (i.e. mudflats) and wetlands can reach 366 tons/ha and 353 tons/ha, respectively. While upland forest may have an average soil carbon density of only 66 tons/ha, this is expected to continue to increase as forests mature and forest soils sequester additional carbon. The organic rich soils of forested and scrub/shrub wetlands, as well as emergent wetlands, are especially important as storehouse of carbon.

To help inform a broader assessment of the role of New Jersey forests in carbon credit markets, we used the IntCarb model to estimate the potential for carbon sequestration for a typical tract of farmland regenerated into forest land. A typical New Jersey forest is predicted to reach its maximum rate of carbon sequestration at around 75 years with a density of approximately 150 tons/ha (Fig. 26). After the peak growth stage of around 75 years, the amount of carbon stored in the forest stand starts to decline as the stand matures and thins in tree density. Assuming a 100 year time frame, the IntCarb model estimates a forest carbon stock of approximately 140 tons/ha. After year 400, the IntCarb model suggests that New Jersey forests will maintain a relative equilibrium where the amount of carbon fixed and stored annually stored is equal to released carbon with total accumulated carbon stock of approximately 120 tons C/ha maintained indefinitely.

While the IntCarb model is useful in exploring various scenarios, it is still just a model (i.e., our best approximation of reality) and the results should be assessed with a certain degree of skepticism. For instance, the IntCarb model suggests an approximately 25% decline in carbon stocks after forest stands reach maturity till some equilibrium is reached at age 300+ years. Taken to extremes, these results might be misconstrued to suggest a lower value be placed on older growth forests as compared to younger age forests in terms of their carbon sequestration capacity. Further empirical validation is needed to examine the comparative value of forest sequestration capacity, including forest soils, at various forest ages from young to old growth under typical New Jersey conditions. The IntCarb model was also run for average conditions in each physiographic region and thus does not fully account for spatial heterogeneity. Future work should be undertaken to run the IntCarb model in a more fully spatially explicit manner to better estimate the range of conditions across the New Jersey landscape. Additional research is also needed to more fully characterize the degree of uncertainty in the modeling framework to be able to more adequately quantify the degree of uncertainty in carbon flux estimates.

Acknowledgments

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Section 1b: Soil organic carbon accumulation in young, post-agricultural forests of New Jersey

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Introduction

The carbon found in the soil is the largest and most long-lasting pool of carbon in the terrestrial portion of the earth. As much as two thirds of the carbon stored by forest ecosystems is contained in the soils (Dixon et al 1994). Soil carbon is typically thought to occur in several distinct pools, each of which has a different turnover rate. The 'active fraction,' which is composed of microbial biomass and other easily-decomposed substances (such as soluble material leached from fresh litter) has a residence time of months to years, while the 'passive fraction,' which is composed of the organic products of decomposition processes plus cellulose, lignocelluloses, and other structural components of plant tissues, has a residence time of years to decades. Finally, the recalcitrant fraction is composed of lignins, humic materials, and organic materials complexed with soil clay minerals, all of which are highly resistant to decomposition, and have residence times measured in thousands of years. The passive and recalcitrant pools are very resistant to loss from forest disturbance, making them ideal sources of carbon sequestration.

While the soil thus has the potential to sequester carbon reliably for very long periods of time, it accretes very slowly compared to the growth of forest trees and is relatively difficult to measure and verify (Rodghiero et al 2009). It is likely that for mature forests, soil carbon stocks are at an approximate steady state, and little new sequestration could be expected over timescales relevant to a carbon credit program (Chapin et al 2002). However, for young forests on former agricultural land, there is no source of data that would provide a first approximation of either the stock of carbon or the rate of increase of soil carbon.

Former agricultural lands are commonly depleted in soil carbon. Conversion of land to agriculture can result in depletion of soil organic carbon (SOC) stock by up to 40-50% (Schlesinger 1985, Davidson & Ackerman 1993). The restoration of forests on these lands provides an opportunity to accumulate carbon in these soils at rates that can be estimated and used as the basis of carbon credit programs (Ross et al 2002, Lal 2005). Large amounts of former agricultural land in New Jersey have reverted to forest over the past 50 years. Estimating the rate of soil organic carbon accretion in these ecosystems is highly relevant to the planning and implementation of forest carbon sequestration projects.

We estimated soil organic carbon stocks and calculated rates of soil carbon accumulation for ten pairs of agricultural and forested sites in New Jersey. Our goals were two-fold: (1) to provide a reasonable estimate of SOC accretion rates for young forests of New Jersey, and (2) to characterize general regional differences in SOC stocks and accretion rates among the state's physiographic provinces. These preliminary results may provide a useful baseline for determining the sequestration potential of New Jersey's forest soils.

Methods

1. Site selection

We selected 10 site pairs distributed throughout the state (20 total sites). Each site pair consisted of a young forest and productive agricultural land, located on the same soil type (table 1). Site pairs were located within all of New Jersey's geomorphic provinces, and effort was made to target major agricultural soils as listed in the NRCS New Jersey Important Farmlands Inventory (http://www.nj.nrcs.usda.gov/technical/soils/primefarm.html).

Finding site pairs that matched our criteria proved more difficult than anticipated, so we were unable to consistently use prime agricultural soils. Many site pairs used forest and agricultural land in close proximity, but in some cases we accepted sites at considerable distances from each other. This was particularly true in the outer coastal plain, where we had difficultly locating forests on abandoned farmland. Much of the historical agricultural land of this region is still in production today.

Site selection was conducted by comparing land cover between historical (1935) and current (2007) aerial photographs. Forested sites were only selected if the area was under agricultural production in the historical aerial photos. Soil maps were used to ensure that site pairs were on the same soil type.

Table 1: Location and soil type of agricultural and forested site pairs

County	Physiographic region	Soil Type
Cape May/Cumberland	OCP	Ingleside*
Hunterdon	H	Klinesville channery loam
Mercer	P	Bucks silt loam*
Monmouth	ICP	Tinton sandy loam
Morris	H	Gladstone Gravelly Loam
Ocean	OCP	Downer loam*
Salem/Cape May	OCP	Hammonton loamy sand*
Somerset	P	Penn silt loam*
Sussex	RV	Hazen-Hoosic complex
Warren	RV	Netcong loam*

*denotes prime agricultural soils

2. Data collection and sample processing

At each site, soil samples were taken at 5 points along a 20 m transect. Soil was sampled at three depths: 0-10 cm, 10-20 cm, and 20-30 cm. These depths comprise the portion of the soil strata in which significant carbon accumulation may be expected over a period of 50 years. Soil samples were extracted using bulk density cores, small metal cylinders of a consistent volume. Cores were carefully inserted into the soil using a knife to minimize compaction.

In forested sites, litter samples were also taken using a 400 cm^2 plot frame. Twigs and leaves that were partially out of the plot were carefully clipped along the frame edges with scissors. Care was taken to ensure that all of the litter material within the plot was collected.

In the laboratory, soil samples were oven dried for 24 hours at 105 ^{o}C to obtain a dry mass. They were then passed through a 2 mm sieve to separate the fine soil fraction from the coarse (>2 mm) material. The fine soil material was ground and homogenized using an electric grinder. Sub-samples were taken and sent to a commercial laboratory for analysis of percent carbon by dry combustion (CHN analysis). Litter samples were oven dried at 70 ^{o}C for 24 hours and massed.

3. Estimation of soil and forest floor carbon stocks

Estimation of mineral soil carbon stocks is completed based on three parameters: soil bulk density, the depth of the layer (in this case, 10 cm for each depth increment), and soil organic carbon concentrations (Pearson et al 2007). Bulk density was calculated using the following equation:

(1) soil bulk density = ODW / CV- (RF / PD)

Where:

soil bulk density= bulk density of the <2 mm soil fraction (g/cm^3)
ODW= oven-dried weight of the <2mm soil fraction (g)
CV= volume of the soil sampling core (cm^3)
RF= density of soil fragments >2 mm in size (g/cm^3)

This supplies a bulk density estimate for the fine soil fraction only; the portion of the soil where soil organic carbon is expected to accumulate.

Soil carbon stocks in metric tons per hectare were estimated for all depth increments according to the following equation:

(2) C_{layer} (t / ha) = (soil bulk density (g /cm^3) × soil depth (cm) × % C)

Forest floor litter carbon stocks were calculated as:

(3) C_{litter} (t/ha)= [(litter oven-dry weight (g)/sampling frame area (cm^2)) x 100] x % C

Total soil carbon stocks (t/ha) were calculated to a depth of 30 cm for all sites as:

(4) $C_{total} = C_{0\text{-}10cm} + C_{10\text{-}20cm} + C_{20\text{-}30cm} + C_{litter}$

C_{litter} estimations were included when calculating carbon stocks of forested sites only. Litter samples were not collected at agricultural sites.

4. Estimation of forest soil carbon accretion rates

This study is based on the assumption that currently producing agricultural lands provide reasonable estimates of initial soil carbon concentrations at forested sites prior to abandonment. Therefore carbon accretion rates are estimated as:

(5) $(C_{forest} - C_{agricultural})$ / estimated stand age

Stand ages were estimated using historical aerial photo analysis. All forested sites were active agricultural land in 1935 aerial photographs, but had been abandoned and appeared as young (20-30 year) mixed deciduous/cedar forests in photography from 1975. We therefore assumed a standard age of 60 years for all sites. While there is doubtlessly some variation in stand age, efforts to refine age estimates were deemed unreliable. 60 years represents a reasonable approximation of mean stand age among all of the forests sampled.

5. Statistical analysis

Differences in mean total carbon stocks and carbon accretion rates for forested and agricultural sites were tested for significance using one-way ANOVAs. Two-way ANOVAs were used to analyze the interaction of land cover type (forested or agricultural) and profile depth (0-10 cm, 10-20 cm, and 20-30 cm).

Results

1. Carbon stocks

Our results suggest an overall increase in total soil carbon stocks of post-agricultural forests when compared to active agricultural land. Mean carbon density was at least 2 tons/hectare greater when all forested and all agricultural sites were taken together (figure 1). Differences in carbon density varied considerably by county. The largest differences were found in Ocean and Cape May counties (ΔC = 24.9 t/ha and ΔC = 34.6 t/ha respectively). The Monmouth county site pair also showed a large ΔC (23.0 t/ha). The three sites with the largest forest carbon stocks were all located in the inner and outer coastal plain physiographic provinces. The lowest differences in carbon density were observed in the Piedmont and Ridge and Valley sites. One forested site in Mercer county actually had a lower carbon density than the agricultural field it was paired with (ΔC = -5.31 t/ha).

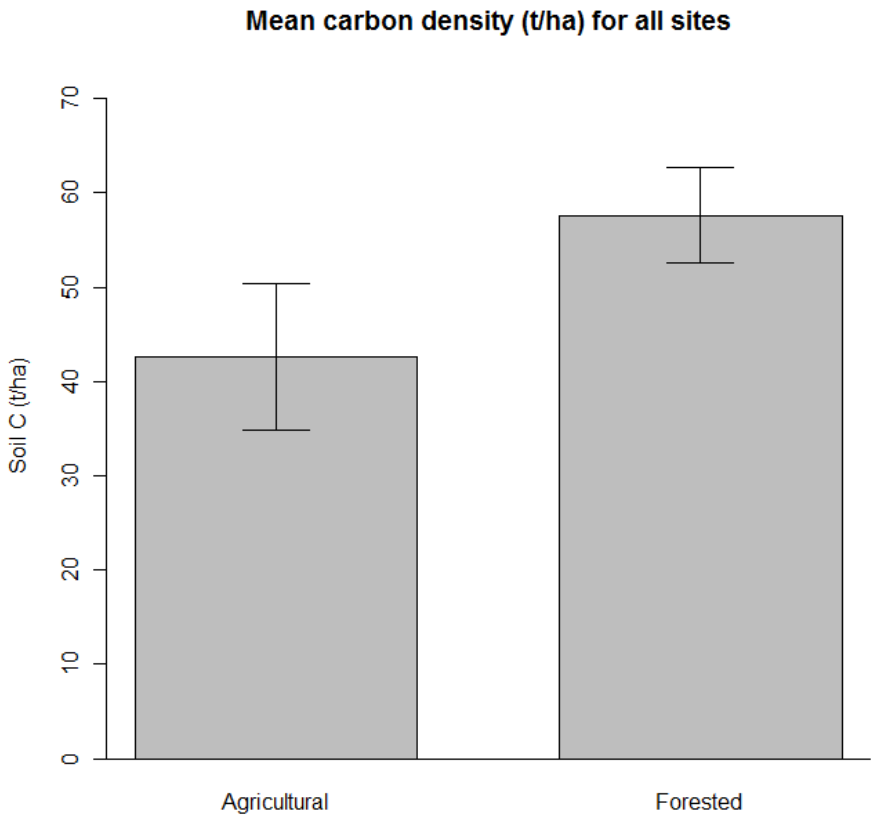

Figure 1: Mean carbon density for all sites in tons per hectare. p = <0.01

Mean increase in soil carbon stocks in forested sites occurred predominantly in the upper 10 cm of the soil profile (figure 2, p = <0.01). The smallest increase was observed in Mercer County (ΔC = 6.6 t/ha). Large changes were again seen on the coastal plain (Ocean: ΔC = 24.0 t/ha, Cape May: ΔC = 22.4 t/ha, Assunpink: ΔC = 15.75 t/ha). Considerable variation in carbon concentration was observed in the 10-20 cm and 20-30 cm zones, though mean contribution to C stocks at these depths were not significantly different for agricultural and forested sites. This pattern was consistent across all site pairs. Contributions of forest litter to total C stocks also varied widely among sites (table 2).

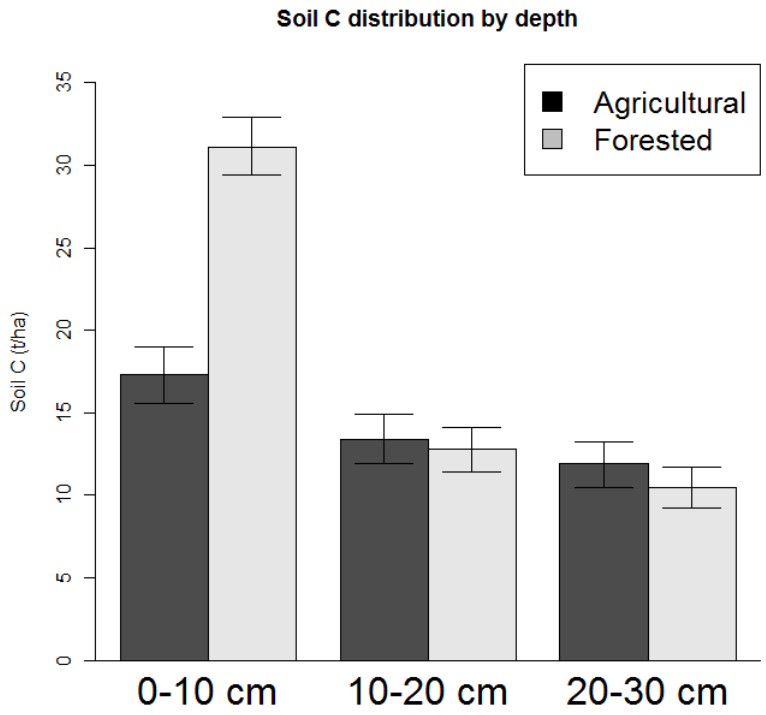

Figure 2: Distribution of soil C within the upper 30 cm of the soil profile for agricultural and forested sites.

Table 2: Mean litter carbon stock for all ten forested sites

	Litter C stock (t/ha)
Cumberland/Cape May	9.29±3.04
Hunterdon	1.86±0.79
Mercer	1.68±1.39
Monmouth	7.07±2.66
Morris	4.34±1.81
Ocean	3.67±1.71
Salem/Cape May	1.89±0.69
Somerset	3.13±1.17
Sussex	3.31±1.11
Warren	3.23±0.92

2. Carbon accretion rates

Mean soil carbon accretion rate for all sites was calculated as 0.25±0.12 t/ha/yr. This value includes the mineral soil to a depth of 30 cm as well as the forest litter layer. The accretion rate for the mineral soil only were also calculated (0.19±0.11 t/ha/yr). Forest litter represents a highly labile pool of carbon, and thus is not expected to contribute to long-term carbon storage. Carbon accretion in the mineral soil layer is important when assessing sequestration capacity. However,

the difference between the above two mean accretion rates was not found to be significant in a Fisher's exact t-test. Table 3 list carbon accretion rates calculated for each site pair.

Table 3: Soil carbon accretion rates for all ten counties

	Mineral soil only (t/ha/yr	Mineral soil + litter (t/ha/yr
Cumberland/Cape May	0.09	0.24
Hunterdon	0.07	0.11
Mercer	-0.11	-0.09
Monmouth	0.38	0.38
Morris	0.17	0.25
Ocean	0.35	0.41
Salem/Cape May	0.54	0.58
Somerset	0.23	0.28
Sussex	0.11	0.17
Warren	0.13	0.18

The highest carbon accretion rates, both with forest litter and without, were found at site pairs in the coastal plain (Cape May, Cumberland, Monmouth, Ocean, & Salem counties). Carbon accretion rates for the Piedmont and Highlands were variable, ranging from moderately high (Somerset: 0.28 t/ha/yr) to negative (Mercer: -0.09 t/ha/yr). Sites in the Ridge and Valley province, in Sussex and Warren counties, were slightly below the state-wide average carbon accretion rate.

Discussion & Conclusions

Our findings suggest that annual soil carbon accretion rates range between approximately 0.1-0.3 t/ha/yr for young, post-agricultural forests of New Jersey. This translates to an average annual sequestration capacity of 10-30 tons for a 100 hectare field undergoing forest succession when taken over a 60 year time frame. These results demonstrate that soil carbon accumulation in young forests can make significant contributions to carbon sequestration projects.

As with the results of the state-wide soil carbon survey reported in section 1A, we found both the highest carbon densities and the highest carbon accretion rates in rural areas of the Inner & Outer Coastal Plain. Rates of carbon accumulation calculated from site pairs in the Piedmont, Highlands, and Ridge & Valley were mostly at or near the state-wide mean. The one exception is the site pair in Mercer County, which showed a net decrease in soil carbon density between the agricultural and forested site. This site pair included Honey Brook Farm in Hamilton Township, the only organic farm sampled during the study. That a higher carbon density was recorded in the agricultural field than in the forest here is likely due to within site variation, perhaps related to soil amendment practices typical of organic farming.

Our results suggest that most soil carbon accretion following agricultural abandonment occurs in the litter layer and in the upper 10 cm of the soil profile. This agrees with patterns seen in other, long-term field studies tracking SOC accumulation in young post-agricultural forests (Richter et al 1999). It is important to note that a considerable portion of the soil organic carbon present in these pools will be in highly labile forms, and thus lack the permanence necessary to

contribute to long-term soil carbon sequestration. To gain a better understanding of long term soil carbon storage separate estimates for the labile, passive, and recalcitrant soil carbon fractions must be derived.

While we have demonstrated that young forests on New Jersey soils are accumulating soil carbon, and shown some basic regional differences in carbon accretion rates, the considerable variation among the site pairs must be noted. Soil organic carbon accumulation is determined by the rates of soil carbon fluxes such as decomposition and soil respiration (Chapin 2002). These processes are affected by a variety of abiotic and biotic factors including soil structure, climate, and vegetative community composition (Post et al 1982, Kutsch et al 2009). Differences in agricultural practices can also drive variability in soil organic carbon stocks among sites (Hoover 2003). Future studies should include multiple replicates on fewer soil types to reduce sources of error and refine estimated soil organic carbon accretion rates. Efforts should also be made to locate forested sites of a similar community, and agricultural sites that have been subjected to comparable management regimes.

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Section 2: Quantification of the capacity to sustainably produce wood-based biomass renewable energy in NJ and thereby reduce reliance on fossil-based non-renewable energy resources.

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Introduction

The broader objective of the work performed in this section is to determine the potential supply of renewable energy in New Jersey from woody biomass. More specific objectives were to quantify the availability of woody biomass that can be classified as Class I and Class II renewable energy. Class I type materials include Forestry Residues, Primary and Secondary Forestry Products Industry Residues, Urban Forestry and Landscaping Residues, and Bioenergy Crops, and Class II material include Construction and Demolition Waste sources. The basis for calculating the amount of woody biomass that is a Class I resource was based in part, as is the calculation of carbon sequestered in New Jersey forests, on data available from the USDA Forest Service Forest Inventory and Analysis. The amount of woody biomass that is a Class II resource was calculated from a survey of the various public and private entities that generate, recycle, and dispose of this material.

Determining the quantities of wood-based biomass

The ultimate goal of the work performed in this section is to determine the potential supply of renewable energy in New Jersey from woody biomass. In order to accomplish this, it is first necessary to specify what woody biomass is and how it may be classified as either Class I or Class II Renewable Energy. The source document for these definitions is the New Jersey Renewable Portfolio Standard.[1] From subchapter 2, part 2, Definitions (14:8-2.2): "Biomass" has the same meaning as that assigned to this term in Executive Order No. 13134, published in the Federal Register on August 16, 1999. This Executive Order defines biomass as "…any organic matter that is available on a renewable or recurring basis (excluding old-growth timber), including dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, wood and wood residues, animal wastes, and other waste materials." Further, biomass is considered a renewable fuel (from 14:8-2.2) when it is "naturally regenerated over a short time scale" and is derived from "photosynthetic energy stored in biomass."

Woody biomass, as used here, refers to biomass containing a substantial amount of woody material—in technical terms, the secondary xylem in the stems, branches, and boles of trees and the stems and branches of other woody plants. The sources of woody biomass considered here are the various wastes, residues, and by-products of forestry (silviculture) and the primary and secondary forest-products industries. The woody biomass considered here does

[01] New Jersey Administrative Code § 14:8-2

not include farm (agriculture) crops or their residues, aquatic plants, animal wastes, and food processing wastes.

The energy generated from woody biomass, whether the woody biomass is used as a fuel directly (combusted) or used as a feedstock for producing another form of fuel (densified fuels, alcohol, or methane, for example), may qualify as Class I Renewable Energy if it used to generate electricity and the source of the woody biomass is one of the following:

1. A bioenergy crop—that is to say, a woody biomass crop "cultivated and harvested specifically for use as a fuel for the purpose of generating electricity"—including woody crops grown in and harvested from biomass energy plantations;[2]
2. "Wood from the thinning or trimming of trees and/or the forest floor, provided that" the woody biomass recovered is clean and uncontaminated by other materials and is not harvested from old-growth forests;[3] and
3. Wood wastes and by-products recovered from primary and secondary forest-products industries (excluding black liquor) and ground or shredded pallets or other scrap wood from Class B recycling facilities or elsewhere, all clean and uncontaminated.[4]

The kinds of woody biomass specifically excluded from consideration as a Class I resource include treated, painted, or chemically coated wood; the woody fraction of municipal solid waste; the woody component of construction and demolition debris; any woody biomass recovered from old-growth forests; and commercial forest products from standing forests.[5]

Language in 14:8-2.5 (d) in part reads "Electricity produced through combustion of the following types of biomass shall qualify as Class I renewable energy...," including, from 14:8-2.5 (d) 2, "Wood from the thinning and trimming of trees and/or from the forest floor...." Language in 14:8-2.5 (l) reads "Electricity produced through combustion of the following substances shall not qualify as Class I renewable energy for the purposes of this subchapter," including, from 14:8-2.5 (l) 7, "Wood harvested from a standing forest...."

These subsections of the Renewable Portfolio Standard explicitly say that wood harvested from a standing forest does not qualify as a Class I resource, but that the thinnings or trimmings of trees (which logically would include the thinnings and trimmings of trees in a standing forest) do qualify as a Class I resource. Taken together, these rules may be interpreted (pending official determination) such that

- The woody portion of trees (including tops, branches, and boles) removed during commercial thinning (collectively referred to as thinning residues) from some portion of standing forest (that commercial thinning having been accomplished in a sustainable manner) may qualify as a Class I resource and
- The woody portions remaining after commercial harvesting (tops and branches) as well as the woody portion of trees lacking commercial value not harvested (collectively referred to as logging residues) from some portion of standing forest (that harvest likewise being accomplished in a sustainable manner) also may qualify as a Class I resource.

Language in 14:8-2.5 (e) in part reads, "Electricity produced through combustion of a type of biomass not described in this section may qualify as Class I renewable energy for the purposes of this subchapter, provided NJDEP provides Board staff with a biomass

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New Jersey Administrative Code
[02] 14:8-2.5 (d) 1
[03] 14:8-2.5 (d) 2
[04] 14:8-2.5 (d) 4 i and ii
[05] 14:8-2.5 (l) 1 - 7

sustainability determination…." Though not specified in the Renewable Portfolio Standard, the sustainability determination may be reviewed by the New Jersey Forest Service and be based on certification such as can be provided by the Forest Stewardship Council.[6] This sustainability determination ultimately may be required for qualifying the residues generated by forestry thinning and harvesting activities as Class I resources.

For the purposes of the assessment undertaken here, the forestry residues generated by thinning or harvesting (all done in a sustainable manner) will be included in the category of material previously identified as wood from the thinning or trimming of trees and/or the forest floor. Urban forestry and landscaping residues likewise are included in the category identified as wood from the thinning of trees and/or the forest floor.

Lastly, the electricity generated by a resource recovery unit may qualify as Class II Renewable Energy, provided that such a facility meets the procedural and environmental requirements specified by the Renewable Energy Portfolio Standard. The woody biomass incinerated by such units can include the woody or cellulosic fraction of municipal solid waste and the unrecyclable portions of certain industrial wood wastes.

1.1 Selected Class I Resources in New Jersey

Four sources of Class I resources are examined in this report. They are bioenergy crops, forestry residues, forest-products-industry residues, and urban forestry and landscaping residues. As shown in the Table 1, the potential sustainable annual production of woody biomass from these four sources of Class I resources could be as much as 3,888,000 tons of woody biomass per year.[7] The total amount in the table represents an upper limit of what might be produced: not all farmers will grow bioenergy crops on every acre of marginal farmland that is available; not every available acre of timberland will be managed for timber crops; not all forest industry residues will be recoverable; just as not all tree service and landscaping residues will be recoverable.

It must stressed that the amounts shown in the following table represent an upward potential, a theoretical maximum of what might be produced, a ceiling to be used only for purposes of planning. Biomass is a local resource. As such, local production depends on local conditions that are not observable in the countywide and statewide statistics that were used to assess the overall potential. In reality, any number of conditions might limit what actually could be produced. Reasons that the theoretical potential supply might not be recoverable include: (1) local, county, or state regulation, such as management restrictions imposed by the Pinelands Commission or as imposed by the endangered species act; (2) good forestry practices, such as harvesting restrictions in wetlands; (3) economics of production, such as the increased cost of hauling materials to a distant market; and (4) personal preference, such as a farmers and landowners wanting to manage agricultural and forest land for uses other than biomass production.

[06] http://www.fscus.org/

[07] All tonnages reported here are calculated based on the assumption of an inherent moisture content of 45 percent on a green-weight basis.

Table 1. Theoretical Potential Annual Production of Woody Biomass for Generating

Source	**Tons × 1,000**
Bioenergy Crops	890
Forestry Residues	921
Primary and Secondary Forest Products Industry Residues	135
Urban Forestry and Landscaping Residues	1,942
Total	3,888

Class I Renewable Energy

It is somewhat surprising, though perhaps not totally unexpected, that the single largest potential supply of woody biomass is urban forestry and landscaping residues, given that New Jersey is so highly urbanized and densely populated. A similar observation can be made concerning the large potential supply of bioenergy crops. The potential supply of forestry residues is likewise substantial though the forestry industry in New Jersey is much reduced from what it once was.

Assuming the heating value of moisture-free wood is 8600 Btu/lb and the moisture content of the woody biomass in the table is 45 percent on a green-weight basis, then the annual production of 3,888,000 tons of biomass identified above has a fuel value of 36.78×10^{12} Btu. If all this woody biomass is fired as a fuel in power plants that are the equivalent of a modern fifty-megawatt wood-fired power plant with a heat rate of 10,200 Btu/kWh and a capacity factor of 86 percent (Ragland 2000), then the total output of electricity will be approximately 3.6 billion kilowatt hours from power plants with a total capacity of slightly more than 478 megawatts. According to statistics available from the Energy Information Administration, the average household in the MidAtlantic Region[8] in 2005 consumed 8,514 kilowatt hours per year ("Average Consumption Fuels Used"). Thus, the 3.6 billion kilowatt hours generated with the woody biomass is equal to the amount of electricity consumed by nearly 424,000 of these households.

1.1.1 Bioenergy Crops

One of the goals of this analysis is to determine how much farmland could potentially be used to grow bioenergy crops. The calculations excluded prime farmland, where most of the food and ornamental crops are grown, and focused on the less productive farmland, those lands categorized as Farmland of Statewide Importance or "marginal soils". Farmland is judged to be marginal for a variety reasons; it may be too dry or too wet, too susceptible to erosion, or lacking fertility. New Jersey farms produce a wide variety of high value products. On a profit per acre basis, it will be very difficult for bioenergy crops to compete with the food and ornamental crops grown on New Jersey's prime farmland because bioenergy crops typically have a lower profit per acre. However, marginal soils usually have reduced crop yields. Marginal soils could become more productive by growing a bioenergy crop that is adapted to the soil conditions and improves the quality of those soils by increasing the organic carbon

[08] New Jersey, New York, and Pennsylvania

level. Bioenergy crops may be able to compete economically with conventional crops on marginal soils while protecting the soil better than an annual crop would.
The bioenergy crops under consideration here are short-rotation tree crops grown on and harvested from so-called "energy plantations." The plantation culture of tree crops is well-known and widely practiced throughout much of the world. In the southern United States, for example, southern pines (softwoods) have been planted extensively as a source or pulpwood and timber. Energy crops, in contrast, typically are composed of hardwoods, such as hybrid poplar or hybrid willow, and are grown on comparatively shorter rotations (shorter intervals between harvests) and at denser plantings (more trees per acre).

An important element of the rationale for growing woody biomass crops is that such crops can be grown using less intensive production techniques on marginal farmland, thereby avoiding competition with food production on better quality land.

- While the production of any crop will require an adequate supply of water, the annual fall of deciduous leaves will contribute to a layer of organic material on top of the soil as well as an increase in organic matter in the soil's upper levels that together will act to hold water and slow its percolation through the soil, thereby making water consumption over time more efficient.
- Given the large number of hardwood species indigenous to the United States, it is likely that hardwood energy crops can be developed from trees, such as sycamore, that grow well on wetter soils.
- Short-rotation tree crops are grown on multiyear rotations. In addition, certain hardwoods will sprout vigorously from the stump when cut down (a practice known as coppicing). Once planted, such woody biomass crops would not require turning over the soil (plowing, planting, cultivation, etc.) thereby reducing soil erosion, whether by wind or water.
- Cultivated hybrids of native willow and poplars, as examples of short-rotation tree crops, are referred to in ecological terms as pioneers—that is to say, they are typical of trees that colonize bare ground. Hence, they grow on mineralized soils and they will respond to applications of conventional fertilizers. Nutrients, however, will be recycled back to the soil in the annual fall of deciduous leaves, thereby reducing the longer-term need for additional fertilizer.

The amounts of prime and marginal soils that are available in NJ are listed in the Table 2 below. This table was compiled by doing a database search by county for Prime Farmland and Farmland of Statewide Importance (NRCS SSURGO). Then the NJ DEP Land Use/ Land Cover 2002 updated database, Level 1 - Agriculture Use Category, was cross referenced with the database. This work was performed by the Walton Center for Remote and Spatial Analysis, School of Environmental and Biological Sciences, Rutgers University (Hasse and Lathrop, 2008). The cross reference deducted any land that was not currently in agriculture from the county totals for the specific soils. They have been grouped by the USDA NASS district designations of North, Central, and South in order to get a regional view of the amounts of acreage that is available.

There is a significant amount of marginal farmland in NJ. In total, there are approximately 178,000 acres, or approximately 1/3 of all farmland, prime and marginal farmland combined. It should be noted that this acreage is currently is being used, or in the not-too-distant past was used, as cropland, pasture, or left fallow—in any case, has not been developed for other uses that would preclude its future use for growing biomass energy crops. It is also possible, where such acreage has been left untended that, as a consequence of the ecological process referred to

as old field succession, this acreage has been substantially recolonized by woody vegetation (shrubs and trees). Assuming a long-term sustainable yield of 5 tons (green-weight basis) per acre per year woody biomass crops grown on marginal farmland in New Jersey could supply as much as 890,000 tons per year of biomass ("Sustainable Production of Woody Biomass for Energy Production", 2002).

Table 2. NJ Farmland Acreage by Category

(All Units in acres)

COUNTY	Marginal Farmland	Prime Farmland
North		
SUSSEX	1,292.90	13,273.40
PASSAIC	19.9	68.8
BERGEN	99.3	170.1
WARREN	10,586.10	35,104.80
MORRIS	3,214.30	8,429.60
ESSEX	-	38.7
HUDSON	-	-
HUNTERDON	37,098.90	34,511.90
SOMERSET	10,138.90	15,267.30
UNION	32	39.5
subtotal	*62,482.30*	*106,904.10*
Central		
MIDDLESEX	3,930.10	12,840.90
MONMOUTH	12,090.30	27,951.00
MERCER	11,564.40	13,704.70
BURLINGTON	18,146.80	45,581.90
OCEAN	3,709.40	1,990.10
subtotal	*49,441.00*	*102,068.70*
South		
CAMDEN	4,373.80	4,161.30
GLOUCESTER	14,739.40	33,101.30
SALEM	19,142.00	57,664.70
ATLANTIC	13,199.40	7,793.70
CUMBERLAND	13,192.00	51,661.00
CAPE MAY	1,664.40	4,293.90
subtotal	*66,311.10*	*158,675.90*
TOTAL	**178,234.30**	**367,648.70**
% of TOTAL	**32.7**	**67.3**

NJ Farmland Acreage by Category
(All Units in acres)

Note: Information for this table was provided by Chris Smith, NJ NRCS, Richard Lathrop, Walton Center for Remote and Spatial Analysis and John Hasse, Rowan University.

1.1.2 Forestry Residues from Sustainable Forestry Practices

The amount of forestland in New Jersey has remained fairly constant at about two million acres throughout the last century and a half (Widmann 2005). In a 1999 forest inventory performed by the U.S. Department of Agriculture Forest Inventory and Analysis (FIA) Program, there were about 2.1 million acres of forestland in New Jersey, including 1,876,000 acres of timberland and 256,000 acres of other forestland (Griffith 2001). The USDA FIA program defines timberland as forestland where commercial timber crops can be grown and harvested. The other forestland includes reserved lands, where timber harvests are restricted, and unproductive forests, where timber harvests are economically impractical. In the ongoing analysis, only timberland will be used for estimating the sustainable production of forestry residues.

In 1999, slightly more than 1,288,000 acres of timberland were held by private owners, including farmers and miscellaneous other corporations, individuals, and others (Griffith 2001). "In New Jersey, sixty-eight percent of the private forest landowners hold fewer than ten acres of forest. Collectively this group owns about ten percent of the forestland, which is mostly used for home sites. Since 1972, the estimated number of these owners with fewer than ten acres of forest has increased by seventy-five percent. Unlike owners of large tracts, these owners are less likely to manage their forests…." (Widmann 2002) Participation by this group of small landowners likely will be further inhibited by the disproportionally large transaction costs associated with managing such small holdings. Therefore, only 1,159,000 acres of privately owned land will be included in this ongoing analysis.

According to the aforementioned forest inventory, nearly 588,000 acres of timberland in New Jersey were held by public owners, including Federal, State, county, and municipal governments (Griffith 2001). It is assumed, however, that all timberland owned by the State of New Jersey should be considered available for sustainable forest management practices. The timberland owned by the State, including both in State Forests and other forestland owned by the State, totals about 475,000 acres (Griffith 2001).

In total, there are 1,634,000 acres of privately and publically owned timberland (87 percent of all timberland in the State) theoretically available for the sustainable production of forestry residues.[9] If one assumes that commercial-grade timber can be grown on an eighty-year rotation, then harvesting one-eightieth of the total timberland available in New Jersey in any given year will insure that forests have sufficient time to regenerate and produce a new crop of commercial-grade timber. Therefore, no more than 20,425 acres of timberland (subject to the caveats stated earlier with regard to Class I woody biomass) can be harvested in any given year.

Reviewing the area in timberland in New Jersey in 1999 by stocking class, more than 62,000 acres were overstocked, more than 927,000 acres were fully stocked, and the remainder, more than 886,000 acres, was moderately stocked, poorly stocked, or nonstocked (Griffith 2001). Assuming that stocking classes are distributed in the same proportion in the timberland being considered in this analysis as in all timberland in the State, there are nearly 862,000 acres of timberland that can be harvested on a sustainable basis that are either fully stocked or overstocked. If harvests are limited to only 20,425 acres per year, then there is acreage enough

[09] Represents the summation of 1,159,000 acres of privately owned and 475,000 acres of state owned timberland available for forestry residues from sustainable forestry practices, as determined by the authors. Those assumptions are explained in the two preceding paragraphs.

to sustain more than forty years of harvesting activity, providing time to manage the remaining nonstocked, poorly stocked, and moderately stocked acres to increase their stocking levels.

It also is assumed that during the course of a sustainable harvest that the wood harvested will be sorted according to its highest valued use. Higher quality logs, for example, will go to a sawmill to be converted into poles or sawn into lumber and only the poorer quality logs will used as a fuel. Reviewing the volume of sawtimber trees in all size classes on timberland in New Jersey in 1999, sixty percent of sawtimber was reported as either grade 1 or 2, the better grades of timber sought after by sawmills; the remaining forty percent of sawtimber was reported as grade 3, 4, or 5, the poorer grades of timber often rejected by sawmills (Griffith 2001). In calculating the potential amount of biomass that can be produced each year from sustained forestry operations, it will be assumed that

- The proportion of the various grades of sawtimber trees is distributed in the same proportion in the timberland being considered in this analysis as in all timberland in the State and
- Poletimber and sawlogs from Grade 1 and 2 trees will not be counted but all of the woody portion of tree in Grades 3, 4, and 5 will be counted in biomass estimates.

The calculation of woody biomass that can be harvested on a sustainable manner therefore will include the branches and entire bole of poletimber and sawtimber trees that are Grade 3, 4, and 5 but only the branches and upper portion of the bole (the upper stem) of all poletimber and sawtimber trees that are Grade 1 and 2. However, the biomass in foliage and stumps and roots of growing stock trees will not be included. In addition, the woody biomass in cull trees and salvable dead trees will be included in biomass estimates though the woody biomass in saplings, seedlings, and shrubs will not.

Based on the foregoing information and assumptions and the additional assumption that wood freshly harvested has an average moisture content of 45 percent (green-weight basis), the amount of woody biomass that can be sustainably harvested can be calculated using estimates of biomass in all trees and shrubs on timberland (Griffith 2001) to be 921,000 tons per year. The forest-products industry in New Jersey is only a small remnant of what it once was; there are far too few foresters and loggers now operating in the State to undertake such an ambitious program as would be required to generate the logging residues estimated above. This estimate represents the total amount that might be harvestable if additional foresters and loggers could be mobilized for such a large-scale undertaking.

The State of New Jersey is situated over parts of three distinct geologic regions—uplands to the northwest, coastal plain to the southeast, and plateau in between. The uplands are characterized by a series of ridges and valleys; the plateau by rolling hills sloping gently toward the coast; and the coastal plain by a series of flat terraces that get progressively lower toward the coast (Vail 2007). Three-quarters of all timberland in the State is to be found in four counties in northwestern New Jersey,[10] mostly uplands, and five counties in southeastern New Jersey,[11] mostly coastal plain. (Griffith 2001) Given the distribution of timberland in New Jersey, one would expect nearly thirty percent of all forestry residues to be generated in the northwestern counties, nearly forty-five percent in the southeastern counties.

[10] Hunterdon, Morris, Sussex, and Warren Counties

[11] Atlantic, Burlington, Cape May, Cumberland, and Ocean Counties

1.1.3 Primary and Secondary Forest Products Industry Residues

The forest products industry is usually divided into two segments, the primary and secondary forest products industries (as shown in the Table 3). Primary wood processors, typically sawmills, are those that convert the logs, bolts, and other materials harvested from forests into lumber, pulp, veneer, and such. Secondary processors typically are those that use the output of primary processors to manufacture products, such as millwork, trusses, containers, and pallets.

Table 3. New Jersey Forest Products Industry[12] (number of establishments)

Sawmills and Planing and Flooring Mills	26
Millwork, Plywood, and Structural Members	84
Wood Containers	37
Miscellaneous Wood Products	38
Household Furniture	223
Office Furniture	15
Public Building And Related Furniture	18
Partitions And Fixtures	111

The number of sawmills in New Jersey has declined over time, from 269 in 1909 to 26 in recent years (Vail 2007). This decrease came about even though the amount of forestland has remained more or less constant and the quantity and quality of timber resources has increased during the last several decades. What timber is harvested these days, for the most part, is trucked to sawmills in adjacent states. In 1986, for example, New Jersey exported 4.8 million board feet of sawlogs to New York and Pennsylvania (Wharton 1993).

Of the twenty-six sawmills recently operating in New Jersey, ten are stationary facilities now mostly shut down but operated occasionally by their mostly-retired owners. The remaining sawmills are smaller mobile mills, typically a band saw and hydraulically powered log handler built on a trailer that can be pulled behind a pickup truck to various locations for custom sawing jobs (Lempicki 2009). The estimated annual production of unused, recoverable residues generated by the primary forest products industry in New Jersey is 31,000 tons (Milbrandt 2005).

The secondary forest products industry in New Jersey is profiled in the preceding table. Note that the largest of the secondary manufacturers are those producing household furniture, partitions and fixtures, and millwork. The miscellaneous wood products category includes a wide variety of smaller manufacturers, including those producing art and engineering supplies; musical instrument cases, drum sticks, and pipe organs; industrial patterns and models; frames for pictures and mirrors; billiard tables and gymnasium equipment; toys, models, and playground equipment; caskets; and wooden handles (Lempicki 2009). Certain caveats should be noted when interpreting the data presented in the table: some individual establishments are listed under more than one category; some of the sawmills produce both primary (lumber) and

[12] Anon. 2002

secondary (fencing or flooring) products; and there is, in a few cases, some overlap between categories.

The estimated annual production of unused, recoverable residues produced by the secondary forest products industry in New Jersey is 104,000 tons (Milbrandt 2005). The challenges to recovering and using this material include the widely different sizes and composition of materials, including the presence of glues and coatings; a large number of small producers; and a perceived inconvenience of disposal, including poorly established infrastructure for collection and cost-effective transport of relatively small amounts.

The data used to estimate wastes and by-products of the primary and secondary forest products industry was taken from a recent estimate of such materials (Milbrandt 2005), which estimated residue production based on parametrics developed some years earlier from the study of biomass wastes generated in thirty randomly selected metropolitan areas in the United States (Wiltsee 1998). The value of this approach is that it allows one to estimate residue production based on information readily available from the U. S. Census.

1.1.4 Urban Forestry and Landscaping Residues

Urban forestry and landscaping residues include a variety of woody and nonwoody materials generated by commercial tree service companies; commercial entities that specialize in periodically removing the vegetation growing on powerline, pipeline, transportation, and other rights-of-way; and land clearing companies. There are a large number of tree service companies operating in the state of New Jersey, including 151 commercial entities certified by the New Jersey Forestry Service as Certified Tree Experts (“Tree Professionals for Hire” 2010). Of these, 123 specialize in urban tree removal, sixteen in clearing utility rights-of-way, and twelve offering a combination of both services. Twenty-eight land clearing companies also were identified as working in New Jersey ("New Jersey Land Clearing Companies" 2010)

During the course of the research reported here, a survey was undertaken of the tree service and land clearing companies. This survey consisted of a one-page questionnaire mailed to each of the companies identified in the previous paragraph. The response from the survey was such that no reliable estimate could be made of the overall production of urban forestry and landscaping residues. However, the survey response did confirm previously gathered information concerning the structure of the industry. The survey also received a strong response in favor of utilizing woody biomass for bioenergy.

Tree service companies can be characterized by a large number of small companies, some no more than a single person and a truck, and a few larger companies. In addition, some of the smaller entities work as franchisees of large national corporations, such as Asplundh Tree Experts and Davey Tree Experts. Land clearing contractors can be similarly categorized; in New Jersey there is one relatively large company and a number of smaller ones, some of which are tree service companies and some of which are farmers that secondarily provide land clearing services.

These various commercial entities generate woody biomass in several forms, including logs, tops and branches of trees and large shrubs, chipped materials, and a mixture of any or all of these materials. Though explicitly not counted in the following estimates, some of these commercial entities also generate tree stumps and nonwoody leaves and grass. Tree stumps are not included in the following estimate because of the soil and stones potentially adhering the stumps; leaves and grass are not included because of their relatively low fuel value and high mineral content. They are also not considered to be wood-based biomass.

It has been estimated that nearly 2,775,000 tons[13] of urban forestry and landscaping residues (as characterized in the previous paragraph) was generated by the aforementioned commercial entities in New Jersey in 1994. Chipped material accounted for 64 percent and logs accounted for 33 percent of the total. Of the total amount, about seventy percent, more than 1,942,000 tons, was estimated to be recoverable (Rooney 1998).

The area of greatest population density in New Jersey is a corridor surrounding either side of a line running from Philadelphia in the southwest to New York City in the northeast. According to the last census, the combined population of Bergen, Essex, Hudson, Mercer, Middlesex, Morris, Passaic, Somerset and Union (counties touched by that corridor) is 5,166,941, slightly more than sixty percent of the total population of New Jersey ("New Jersey Population Estimates" 2008). These nine counties, however, account for only twenty-seven percent of all the land area in the State (Widmann 2001). Urban forestry and landscaping residues typically are produced in or around cities—that is to say, areas where there are large numbers of people living. On this basis, it is reasonable to expect a substantial amount of all the forestry and landscaping residues in New Jersey to be produced in the nine highly urbanized counties identified above.

The data used to estimate urban forestry and landscaping residues was not taken from more recent estimates (Milbrandt 2005), but from a similar study undertaken earlier (Rooney 1998), estimates in the latter report was based on data collected, in the case of urban forestry and landscaping residues in particular, from earlier research reported in 1994 (Anon. 1994). Data from the more recent study (Milbrandt 2005) was deemed unacceptable for the purposes of this research because urban forestry and landscaping residues were included along with construction and demolition debris in a much broader category of urban wood wastes.

The choice was made to use the older information because it defined the residues just as this report does (tree trimmings) and gathers data from the same group of entities (tree care, power line maintenance, and land clearing companies). Furthermore, the estimates in the more recent report are based largely on research undertaken in 1998 (Wiltsee 1998) as opposed to similar estimates in the earlier report based on research undertaken in 1994 (Whittier et al. 1995), not so much of a difference as suggested by the publication dates of the two primary documents.

1.2 Selected Class II Resources in New Jersey

1.2.1 Construction and Demolition Waste

Construction and demolition (C&D) waste contains wood products that, if separated properly from the rest of the comingled materials, could be used to produce bioenergy. The amount of wood in mixed C&D is quite variable. A biomass inventory conducted by the New Jersey Agricultural Experiment Station (NJAES) in 2007 used a conservative, average figure of 33% wood by weight in mixed C&D (Brennan 2007). C&D wood is composed primarily of dimensional lumber, plywood, chipboard, pallets, furniture, and pressure treated wood. These materials are sometimes separated, at the source, from the other construction and demolition waste in order to dispose of them separately for a lower tipping fee (disposal charge). C&D wood will often have a moisture content below 25%. It is also generated on a year-round basis. The low moisture content and year round availability make it a good candidate for bioenergy

[13] assuming an as-harvested moisture content of 45 percent measured on a green-weight basis

production especially since much of it is destined for a landfill which has economic and environmental cost associated with it.

C&D wood is currently considered Class II biomass. However, there is some willingness to consider it a Class I biomass if it is separated at the source, does not contain pressure treated wood, and is converted to energy in a low emissions technology system (DEP meeting notes, 2009). For the purposes of this report, we will classify this source of woody biomass as Class II biomass. Further refinement of the designation of wood in this category will occur on a case-by-case basis as is established under the current regulations.

The total amount of non-recycled C&D wood available in New Jersey in 2007 (the most recent year which data is available) was estimated to be 497,000 tons. Table 4 lists the totals by county. As with other sources of wood in New Jersey, C&D wood does have alternate uses. The pallets and dimensional lumber (what the industry refers to as clean wood waste) are often separated and chipped for landscape mulch and used as a bulking agent in composting operations. The plywood, chipboard, furniture, and painted wood is chipped and used by landfills for daily cover. The pressure treated lumber is separated and transported to other states where is used for energy production in specialized biomass combustors.

Table 4. NJ C&D Waste by County 2007 Data

County	Tons
Atlantic	82,228
Bergen	145,196
Burlington	39,768
Camden	58,082
Cape May	70,539
Cumberland	5,171
Essex	146,887
Gloucester	30,855
Hudson	116,484
Hunterdon	14,288
Mercer	50,077
Middlesex	81,098
Monmouth	157,869
Morris	75,560
Ocean	71,233
Passaic	102,349
Salem	13,041
Somerset	94,619
Sussex	2,015
Union	86,346
Warren	1,332
Total	**1,445,037**
Wood	**476,862**

Footnote: Information provided by NJDEP Solid and Hazardous Waste Program

The 2009 tipping fees for C&D waste ranges from $0 to $125.00 per ton (NJDEP 2009). The variability in tipping fee is due to the disposal location as well as the percent and

type of wood in the C&D mixture. There were no cases found where the hauler was being paid for the unprocessed C&D wood waste.

Conversion Technology Assessment

In this section of the report, biomass conversion technologies will be evaluated for the production of electricity, heat, and transportation fuel. This evaluation will focus on technologies that are commercially available or at the commercial prototype level (3 to 5 years from commercial production). The technologies will be grouped by general category and outputs. Examples will be given in cases where commercial systems are operating.

2.1 Electricity and Heat Production

2.1.1 Direct Combustion

Simplest of all the direct combustion technologies are the "pile" burners, which include stoves and fireplace inserts used in residential applications, some furnaces used in commercial and institutional applications, and some simpler wood-fired combustors (the older "Dutch oven" combustors, for example) used in some older and smaller industrial applications. Cord wood, pellets (in the case of residential applications), briquettes, or wood chips (in the case of commercial or institutional applications), or a variety of wood wastes (in the case of industrial applications) are literally piled up in the combustion chamber, ignited, and burned to generate hot exhaust gases as a source of heat. Wood ash is removed and disposed of manually. The entire process is done on a batch-by-batch basis. The average net efficiency of a well-maintained, wood-fired stove is upwards of 50%.

In some midsize or larger commercial and institutional applications and midsized or larger industrial and utility applications, fuel is mechanically fed continuously into a combustor and burned on a stationary sloping grate, a traveling grate, or a vibrating gate. Similarly, ash is mechanically removed continuously after combustion is complete. In some cases, hot exhaust gas is used directly as a source of heating; more often, the heat in the exhaust gas is used in a boiler to generate hot water and/or steam, which can be used for space heating in commercial and institutional applications, for generating electric power and/or process heat in industrial applications, and for generating power in utility applications.

Compared to pile burners, combustors with grates offer more control of the combustion process and higher combustion efficiencies. A possible disadvantage is likely restrictions on the range of acceptable fuel type, size, moisture content, and thereby a greater need for fuel processing prior to combustion.

In the larger industrial and utility applications, biomass fuels may be combusted in fluidized-bed boilers. Fluidized-bed boilers employ either bubbling-bed or circulating-fluid-bed technology. In both cases fuel is conveyed into a heated bed of inert material, such as sand, where combustion of the fuel is initiated and sustained by the heat of the inert bed material. In the bubbling bed combustor, air is injected by way of a plenum underneath the bed causes the bed to be agitated not unlike water boiling in a pan with bubbles of steam escaping. In the case of the circulating fluid bed, the mixture of inert bed material and fuel is supported entirely by a column of air where bed material and burned fuel exiting the combustion chamber are collected and the inert bed material is re-injected into the bed. Bubbling beds tend to be used in smaller applications; circulating fluidized beds in larger applications.

The advantages of fluid bed combustion are higher combustion efficiencies (45-65%), fuel flexibility, and lower air emissions (both nitrous oxides and sulfur dioxide). These advantages typically outweigh the principal disadvantage of fluid bed combustion, the parasitic energy load required for opening the fans to provide the fluidizing air.

In a limited number of industrial applications, biomass fuels are combusted in suspension-fired combustors, where the fuel is dried and reduced in size to a consistency somewhat like talcum powder, entrained in a column of air, and injected into a combustion chamber. Hot exhaust gases from the combustor are passed through heat exchangers to generate hot water and/or steam. The chief advantage of suspension-fired combustors is high combustion efficiency and small combustor size. The chief disadvantage of this technology is the high parasitic energy loads required to dry and pulverize the fuel.

Overall, there are a number of positives associated with the direct combustion of woody biomass. The technology is relatively simple, with relatively lower capital cost than gasification and other emerging technologies. Equipment using direct combustion of biomass is widely available. Depending on the choice of the aforementioned applications, there is some flexibility in using fuels of different sizes and moisture contents. Investment bankers are comfortable financing the development and deployment of this technology.

Two perceived weaknesses associated with direct combustion applications are that energy conversion efficiencies are lower and emission controls in direct-combustion technologies are not as robust compared to gasification and other emerging technologies. In addition, fairly substantial supplies of water are needed where direct combustion of biomass is used to generate electricity as would also be the case with coal fired power plants.

2.1.2 Co-firing Woody Biomass

Co-firing often refers to the practice of introducing biomass as a supplementary energy source in coal plants. It is a near-term, low cost option for using woody biomass to produce electricity (Bergman et al. 2008). At a total capital cost of $400 to $1250 per kW for direct fire options, it is the lowest cost renewable energy option available including solar, wind, and hydropower (Brennan 2007, Bergman et al. 2008, Easterly and Lindsey 2009). Three methods are under investigation or in commercial practice for co-firing biomass and coal: (1) direct fire, blended feed - mixing the two fuels together before injecting the combined fuels into a combustion chamber, (2) direct fire, separate feed - injecting the two fuels separately into a combustion chamber where they are fired simultaneously; and (3) indirect fire - firing the two fuels separately, where a.) the hot exhaust of a wood combustor is used to preheat combustion air or boiler feed water or b.) a wood gasification unit produces syngas (synthetic gas, for more elaboration refer to Section 2.1.4 Gasification) that is combusted with the coal or used as a NOx re-burning fuel.

In addition to the low capital cost, co-firing results in a net reduction in emissions of sulfur dioxide (in direct proportion to the percent wood being blended), nitrogen oxides (up to a 15% reduction in power plants without NOx controls, and non-renewable carbon dioxide (Brennan 2007, Bergman et al. 2008). Another advantage of co-firing in an area where the infrastructure for woody biomass supply is not yet established is that the coal fired power plant can tolerate fluctuations in the wood supply and cost simply by substituting more coal when wood supplies are short or expensive. This flexibility is not possible for standalone biomass plants.

In the method where wood and coal are mixed together prior to injection into the combustor (the technically simpler approach of the two), both fuels typically require separate pretreatment and handling prior to injection into the combustor. Wood blending up to 2% maximum is recommended in this case for pulverized coal plants, otherwise, wear on the pulverizer will impact performance and maintenance costs or possibly causing fire in the pulverizer due to the fibrous nature of the wood causing friction (Easterly and Lindsey 2009).

In the method where wood and coal are injected separately into the combustion chamber, the utilization rate for wood can be from 2 to 15% of the total energy but the capital costs are higher than the blended feed system. It is very important to consider direct firing methods on a case-by-case basis because there may be difficulties in maintaining the proper flow of air through the combustor to burn the wood (a lighter and fluffier material) completely while burning the coal as efficiently. If the flow of air through the boiler is too powerful, fine woody material may be carried out of the combustion zone before it burns completely, only to catch fire and burn in the heat exchangers or environmental control equipment. Separate injection is the preferred method of the two direct fire methods based on numerous trials (Easterly and Lindsey 2009). Direct co-firing woody biomass in the newer coal plants also utilizes the energy more efficiently than stand-alone biomass power plants with an overall higher heat value (HHV) efficiency of 32% versus 25 to 27% efficiency for the smaller (20 – 50MW), standalone woody biomass power plants (Brennan 2007). Derating of the overall power plant output, due to the lower energy density of the woody biomass, was not observed when co-firing in the 2 – 15% range (EPRI and DOE 1997).

Indirect co-firing provides an opportunity to fire both wood and coal in the same power plant while overcoming the challenges of direct co-firing as previously discussed. Preheating combustion air and boiler feed water is one method of improving power plant efficiency. The technology for burning biomass to generate hot exhaust gas or steam likewise is well understood. Gasification of woody biomass to produce a syngas that can subsequently be combusted in the coal boiler or used as a NOx re-burning fuel is another indirect method of co-firing. In both cases, the ash is kept separate from the coal ash and can possibly be sold as fertilizer. Also, the wood particles do not enter the coal boiler thereby minimizing any adverse effects to the boiler tubes and pollution control system. This method will cost from $2,000 to $2,500 per kW capacity to retrofit an existing coal fired plant. For comparison, a 30 MW standalone woody biomass power plant is estimated to cost from $2,000 to $5,500 per kW capacity depending on the technology utilized (Brennan 2007, Easterly and Lindsey 2009).

The Executive Committee of the International Energy Agency (IEA) reports 234 biomass co-firing installations/trials worldwide in pulverized, fluidized bed, stoker, and cyclone-based coal power plants (IEA Task 32 2002). The Electric Power Research Institute (EPRI), in cooperation with U.S. Department of Energy (DOE), also performed 16 successful demonstrations in the US in the 1990's (EPRI and DOE 1997). Despite the successes, there are additional obstacles for woody biomass co-firing. They include; potential triggering of a new source review (NSR), ineligibility for state renewable energy incentives, fly ash sales may be negatively impacted, and a lack of buy-in from the power plant operations department (Brennan 2007, Easterly and Lindsey 2009).

2.1.3 Scale of Operation

Biomass-fired direct combustion applications tend to fall into four size ranges: small, medium-small, medium-large, and large. Small applications tend to be smaller than the

equivalent of one megawatt in size; medium-small applications range in size from one up to five megawatts; medium-large applications, from five up to fifteen megawatts; and large applications, fifteen to fifty megawatts. Although larger facilities have been proposed from time to time, the largest wood-fired facility with a successful, long-term operating history is the fifty-megawatt, wood-fired McNeil Station operated by Burlington Electric of Burlington, Vermont. When operating at full capacity, this plant consumes about 2,000 green tons of fuelwood chips per day. This rate of fuelwood consumption is comparable to the sustained average daily demand for wood chips by several of the largest pulp mills in the United States and Canada.

Small-scale biomass-fired direct combustion applications (smaller than the equivalent of one megawatt) usually are the stoves and furnaces used to provide space heating, or, rarely, hot water for use in homes and smaller commercial and institutional buildings. The fuel of choice in many cases is stove wood (cordwood split into smaller pieces); though some stoves and furnaces burn fuelwood chips or pellets. Stoves, fireplace inserts, and furnaces burning stove wood for the most part are manually operated (with fuel added and ash removed as needed) while the operation of pellet- or briquette-fired stoves or furnaces can be automated to a greater degree. With good design, attentive operation, and occasionally fitted with catalytic converters, these small applications burn wood fuels relatively efficiently and cleanly.

Medium-small-scale biomass-fired direct combustion applications (the equivalent of from one up to five megawatts) are found in larger commercial and institutional facilities and are often used for space and water heating. In smaller industrial settings, medium-small applications may also be used to generate industrial process heat, such as used for drying lumber in kilns, though in some instances (where biomass wastes are freely available or where there are excessively high waste disposal costs), applications of this size also may be used to cogenerate electricity and steam and/or hot water. Commercial and institutional facilities of this size most often fire wood chips; less often, pellets or briquettes. Industrial facilities tend to fire biomass wastes of various kinds, with coarser materials sometimes reduced in size. The upper size and complexity of these applications tend somewhat to limited by the training and certification required for operators of equipment operating at higher temperature and pressures.

Medium-large-scale biomass-fired direct combustion applications (the equivalent of from five up to fifteen megawatts) are usually found mostly in industrial plants, though such applications also may be found in a few of the largest commercial and institutional facilities and a few of the smallest utility power-generation plants. Forest products industry plants and smaller pulp mills burn whatever wood wastes are available; the remainder of the facilities included in this category typically burn wood chips. With the exception of some stand-alone power plants and perhaps a few others, most applications of this size cogenerate electricity and steam and/or hot water. The thermal output of the cogeneration plants may be used for space heating and other institutional uses (such as laundries and kitchens), for generating industrial process heat, or for supplying heat to district heating systems. Units of this size tend to be operated at higher temperatures and pressures (that is, more efficiently) than comparable medium-small-scale units.

Large-scale biomass-fired direct combustion applications (the equivalent of from fifteen up to fifty megawatts) tend to be utility-operated power plants and a few of the very largest industrial plants, including the larger principally pulp and paper mills. The pulp and paper mills often combust a variety of waste products (including wood, pulp, and paper-making wastes); the remainder of the large-scale facilities usually burn wood chips. While the industrial

facilities and a few of the power plants may cogenerate electricity and steam and/or high-pressure hot water, most power plants generate only electricity. Many of these applications are built with state-of-the-art technology to maximize operating efficiency and minimize costs and pollution.

2.1.4 Gasification

Industrial gasification systems have been around since the 1850s. Essentially it works by cracking complex organic molecules in the presence of a managed amount of oxygen and steam at temperatures ranging from 760-1500°C (1400-2800°F). The product of the gasifier is known as syngas, which is a mixture of primarily hydrogen and carbon monoxide, with smaller amounts of methane, carbon dioxide, and nitrogen present ("How Gasification Works?"). Syngas has a lower energy value than natural gas, but it can still be turned into electricity and heat using a combustion engine or gas turbine. It can also be used as a feedstock for transportation fuel and other chemicals via industrial processes, such as Fischer-Tropsch. There are many commercial gasification plants found around the world, but the majority use fossil fuels as their primary feedstock. Only recently has biomass been looked at as a potential replacement for natural gas and coal in traditional gasification systems.

There are several gasification designs, each with different applications. For smaller biomass power production systems (1 kW to 5 MW thermal), Fixed Bed Downdraft and Fixed Bed Updraft are commonly used. Fixed bed gasifiers are cheaper to build and easier to operate than the fluidized bed gasifiers and produce a syngas suitable for fueling internal combustion engines. Larger biomass power systems in the 1 to 50 MW thermal range tend to use Atmospheric Fluidized Bed Gasifiers. The largest systems (50 to 100 MW thermal) use primarily the Pressurized Fluidized Bed Gasifiers. Fluidized bed gasifiers can tolerate a range of woody biomass sizes, bulk densities, ash levels, and moisture levels (Brennan 2007).

The total installed cost for a typical 1.5 MW fixed bed gasifier with an internal combustion engine generator is approximately $4,000 per kW and have an electrical efficiency of approximately 21%. Waste heat can also be recovered from these systems up to 6,400 BTU per kWh. The total installed cost for the larger 25 MW fluidized bed biomass integrated gasification combined cycle (BIGCC) electric system is between $2,000 and $2,500 per kW and have an electrical efficiency of approximately 37%. The BIGCC system also produces less CO2 emissions per kWh than the simple cycle technologies.

Several companies are pursuing biomass fueled gasification systems. In Güssing Austria, Jenbacher AG funded a project to produce heat and electricity from locally harvested wood. The purpose behind the project was to provide stable energy prices to Austria's least economically developed region. The gasification unit is not a traditional system. It combines both gasification and combustion to produce a high energy syngas that cannot be achieved by other gasifiers. It works by feeding wood chips into the gasifier where the syngas is produced and vented through the top. The syngas is then burned in a Jenbacher reciprocating engine to produce 2 MW of electricity at an electrical efficiency of 30%. Some wood is not completely consumed in the reaction. This residue is fed to the combustion unit to produce heat to run the endothermic gasification process. Flue gases are used to heat water, which in turn is used for district heating. Overall heat and electric efficiencies are 85% (Elsenbruch 2003). An interesting aspect of the combination of gasification and combustion is that it is self regulating. If the temperature drops in the gasifier, smaller amounts of the wood are turned into syngas.

This results in an increase in wood residue which creates more fuel for combustion. Higher temperatures achieved by more combustion raise the temperature of the gasifier to reestablish the equilibrium between the two systems. Another benefit of the Güssing plant is the production of low nitrogen, high Btu syngas. Other wood gasification systems in Europe generally produce syngas with nitrogen contents on average of 50%. The Güssing gasifier reduces this level to 3% to 5%. As a result, the syngas has an energy content of 322 Btu/scf. Also, emissions of pollutants were significantly reduced. Carbon dioxide and sulfur dioxide were reduced by 96%, carbon monoxide was cut by 83%, and hydrocarbons by 60%, as compared to traditional systems.

The University of South Carolina installed a combined heat and power facility (CHP) for one of its campuses that utilizes Nexterra Corporation's gasification technology. 57,000 tons of locally sourced wood, with a moisture content ranging from 25-55% will be consumed each year by the plant. It will produce approximately 1.4 MW of power and 60,000 lbs of high pressure steam that heats the campus. The total price tag for the project was $16 million, but the university will save millions of dollars annually on utility costs ("University of South Carolina Biomass Gasification Project" 2009). The past several years have shown spikes and drops in the price of oil and natural gas leaving entities, such as universities, with uncertainty regarding their utility costs. Employing biomass as an energy source allows the University of South Carolina to reduce the volatility associated with the cost of fossil fuel based power and heat systems.

2.1.5 Pyrolysis

The pyrolysis process, similar to gasification, breaks down complex organic molecules into simpler compounds. However, pyrolysis operates in an oxygen free environment with no steam. The temperature of a unit is directly related to the types of products being generated and is usually 350 – 650 ^{0}C. A higher temperature results in a large fraction of gases. Lower temperatures produce a majority of oils and solids, such as char and ash. Most biomass pyrolysis systems are based upon the production of oils, with char and ash as byproducts. The oils can be directly burned in boilers, stationary combustion engines, and turbines to produce electricity and heat. However, due to its varying composition, pyrolysis oil would need to be refined further in order to be used as transportation fuel ("Bio Oil: Pyrolysis Liquid" 2009). The bio-oil produced is acidic (pH 1.5 to 3.8) and has a high water content (8 to 20%). It also has a high oxygen content, primarily from the water, giving it a medium heating value from 72,000 to 80,000 BTU per gallon (Bergman et al. 2008, USEPA 2009). The leftover biochar and ash could potentially be used for fertilizer. They have also been looked at as a means of sequestering carbon.

Pyrolysis technologies have lagged behind gasification in commercialization, largely due to the products being oils and solids, whose uses are limited compared to syngas. One company, Ensyn, however is looking to change this trend. It is currently operating seven pyrolysis plants, with the largest consuming 100 tons of wood residue per day. Its main products are oils and biochars, which can be sold and further refined (Technology 2009).

Another company, re:Char, is developing a small scale pyrolysis unit that is geared towards using farming residues to produce bio-oil and biochar. They claim that the oil can be used as a heating oil substitute or be upgraded to diesel fuel quality. The residual char has high concentrations of compounds that are essential for plant growth, making it a viable fertilizer. They also state that their char is an effective way of sequestering CO_2. Plants absorb carbon

dioxide and turn it into complex organic compounds ("The re:Char Concept" 2009). When the plant dies, it decomposes back into carbon dioxide, completing the carbon cycle. However, by producing char and using it as a fertilizer, the carbon found in the plant remains in a solid state, resulting in the sequestration of carbon dioxide. The validity of char as an effective means of removing CO_2 from the atmosphere is still being debated (Borel 2009). If pyrolysis oils prove to be an effective substitute for heating oil and the biochar is a viable means for sequestering carbon, this technology could play a major role in biomass to energy conversion.

2.2 Transportation Fuel Production

2.2.1Dilute Acid Hydrolysis

The process of acid hydrolysis has been around for more than a century. Two different processes, known as concentrated acid hydrolysis and dilute acid hydrolysis have been developed. Dilute acid hydrolysis systems are the older of the two technologies, with the first attempt at commercialization occurring in 1898. Both essentially work by taking an acid, usually sulfuric acid, and using it to break down the complicated cellulose structure found in plants that cannot be directly turned into ethanol. The products of the reaction are simple sugars, such as glucose, which can be fermented with conventional technology to produce ethanol. Lignin, an integral part of the cell walls found in plants, is a byproduct of the reaction ("Biomass Program: Concentrated Acid Hydrolysis" 2009). The historical peaks of acid hydrolysis implementation were during World War II, when there was a shortage of traditional resources used to make ethanol. During the oil crisis of the 1970s, there was a push for ethanol production via acid hydrolysis. Germany, Japan, and Russia have built several large scale plants over the past fifty years ("Biomass Program: Dilute Acid Hydrolysis" 2009). Today, there is once again a renewed interest in acid hydrolysis as a means of creating cellulosic ethanol from biomass resources. While there are not as many companies interested in this technology, a few are trying to commercialize the process.

The current yield achieved at the pilot scale level is 40 to 65 gallons of ethanol per dry ton of woody biomass. The cost for a 50 million gallon per year plant is approximately $200 million (Brennan 2007). Dilute acid Hydrolysis also has the ability to produce other valuable chemicals which may help this technology develop more quickly as the demand for "green chemicals" increases.

Blue Fire Ethanol is licensing concentrated acid hydrolysis system developed by Arkenol Inc. They have one operating plant in Japan that is sited next to an existing ethanol production facility. The purpose of the facility is to produce the fermentable sugars needed by the existing plant using wood chips. They are also developing their own ethanol production process on the pilot scale. In 2004, Blue Fire Ethanol had a system that produced 300 liters of ethanol per day. Conversion efficiencies of cellulose to sugars are reliably at 75%. 97% of the sulfuric acid can be recovered and reused in the process, reducing the need for waste disposal and minimizing the environmental footprint of the system ("Izumi Production Facility" 2009). They have yet to produce a stand alone commercial facility, and also have not operated any type of plant in the United States.

Masada Resources Group is another company that has an acid hydrolysis system to produce ethanol from municipal wastes. They had pilot a plant with the Tennessee Valley Authority (TVA) that consumed fifty tons per day of municipal solid waste ("Technology Development" 2009). There was an attempt to build a commercial system in Orange County, New York, however contract disagreements between the county and Masada led to an

abandonment of the project. As of 2007, Masada is pursuing a waste to ethanol plant in the Dominican Republic ("Masada Timeline" 2003). Other companies have similar processes, none of which have working commercial facilities in the United States. Acid hydrolysis appears to be the least developed of the group of technologies.

2.2.2 Enzyme-based Cellulosic Ethanol

Enzyme hydrolysis has become the most watched technology in the world of cellulosic ethanol production. It has been largely viewed as a panacea for all of conventional ethanol's shortcomings. Decreased fossil fuel use during production and the ability to use feedstocks that are not taken from food based crops, such as corn, are a few of the benefits of enzyme hydrolysis cellulosic ethanol production. Enzyme hydrolysis is similar to acid hydrolysis in that it breaks down the cellulose found in plants into simple sugars. However, the means of producing the sugars is different. Enzyme hydrolysis uses biological enzymes to facilitate the conversion of cellulose to sugars ("Cellulosic Ethanol Technology" 2009). Many biotechnology companies have been working to find enzymes that maximize the efficiency of this process. Commercial plants are under construction, with companies racing to develop nothing short of a large scale industry.

The yield of ethanol from the cellulosic ethanol process is projected to be 45 to 60 gallons per ton of dry woody biomass. A 25 million gallon per year plant is projected to cost approximately $125 million to construct (Brennan 2007).

Western Biomass Energy has a pilot running on waste wood in Wyoming. It is rated at 1.5 million gallons of cellulosic ethanol per year. The method employed utilizes the traditional cellulose to sugar to ethanol process. Western Biomass Energy partnered with Novozymes to develop the enzymes. They estimate that forty-five gallons of ethanol are produced for every dry ton of wood consumed. Assuming a higher heating value (HHV) of 19.2 GJ/ton of dry wood and an HHV of 84,000 Btu/gallon of ethanol, with external heat and electricity consumed produced from the combustion of waste lignin, an overall conversion efficiency of approximately 20% is achieved. They plan on building commercial scale units (i.e. 5-10 million gallons per year) after analyzing the performance of their pilot scale project. Western Biomass Energy wants to keep its feedstock resource local, with plans of getting the wood for its plant within a twenty mile radius. Also, co-locating with timber mills and paper plants is also apart of their commercialization plan (Hunt 2009).

Another company, Zeachem, has a different approach to cellulosic ethanol production. It combines both enzymatic and thermochemical processes to produce ethanol. The first step is biological, with enzymes breaking down the cellulose into sugars. Next, the sugars are fermented into acetic acid rather than ethanol. Waste lignin is then gasified to produce syngas, where the hydrogen is removed from the stream. The remaining gas is combusted to generate heat and electricity to run the plant. The acetic acid goes through an esterfication reaction to produce ethyl acetate. Finally the ethyl acetate is combined with the hydrogen from the syngas to produce ethanol. Zeachem's strategic advantage is that it utilizes all of the carbon in the feedstock to produce ethanol. During the fermentation step in traditional ethanol production, large amounts of carbon dioxide are given off. Naturally, all of the carbon found in the feedstock does not get used to produce ethanol. Zeachem reports that it is able to produce 135 gallons of ethanol per dry ton of biomass ("Zeachem Technology Overview" 2009). If the calculations and values for Western Biomass Energy are carried out for Zeachem's process, an overall conversion efficiency of 63% is achieved. They also claim to have ethanol energy

output to fossil fuel input of 12.5:1, which is orders of magnitude higher than the 1.4 : 1 ratio of conventional corn ethanol. In January they raised $34 million to build a biorefinery that implements their process.

2.2.3 Gasification to Ethanol

Range Fuels, a company based in Broomfield, Colorado, has a process for producing cellulosic ethanol via the gasification of wood chips. The syngas is run through a catalyst that turns the mixture into ethanol ("Cellulosic Ethanol Technology" 2009). They have several pilot plants in Colorado, all of which are running on the remains of beetle infested trees. Range Fuels plans to have its first commercial plant up and running by 2010 in Georgia. It will run on local waste wood, and will produce a maximum of 100 million gallons of ethanol per year ("Georgia Commercial Plant" 2009). Transmediair Inc., in Hillsboro, NJ also has pre-commercial activities that will utilize pyrolysis and gasification to produce ethanol.

2.3 Wood-based Biomass Fuel Characteristics

One of the paramount values of wood-based biomass fuels is that they can be considered a renewable resource. Biomass is composed largely of carbon, that in the short-term, is taken up from the atmosphere as forestry and farm crops grow. The carbon dioxide that is a by-product of turning woody biomass into energy can then be recycled, again in the short term, through the atmosphere into new crop growth. Woody biomass typically contains very little sulfur compared to coal or petroleum-based fuels thereby generating lower sulfur dioxide emissions in exhaust gases.

Combustion of woody biomass typically produces little ash (0.5 % by weight). Tree bark, which may contain a significant amount of entrained dirt, in general has a higher ash content (3.5%). With very few exceptions, biomass has a lower ash content than does coal, lignite, or peat. Moreover, the ash produced by converting wood-based biomass to energy contains none of the heavy metals (mercury, cadmium, nickel, or molybdenum, for example) that may be found in some coals or petroleum-based fuels.

2.3.1 Energy Density

One of the primary disadvantages of biomass fuels is their low energy density. As a general rule of thumb, wood has slightly less than one-third the density (pounds per cubic foot) of coal and about half the heating value (BTUs per pound) of coal. Transportation for delivering from the supply site to the bioenergy conversion site is the primary expense of wood-based biomass fuel (Bergman 2008). Therefore, the cost of hauling biomass is proportionally greater and the economic haul distances are shorter than for conventional fossil fuels. Unprocessed woody biomass fuels are best used as a local fuel resource in distributed generation applications.

Because the energy density of unprocessed woody biomass is low and the handling process is difficult, several technologies are being employed to overcome these obstacles. The following is a summary of current technologies:

Chipping is the most basic processing technologies and is accomplished by equipment that can be transported to the working site. Tub grinders and rotary wheel chippers being the most common. Chipping allows the woody biomass to be handled in bulk, similar to coal, and during transport it takes up less volume than whole branches and bulk lumber. The size of the

chipped wood will often range from 2 to 4 inches with the smaller sizes requiring more energy to produce. Smaller "sawdust sized" (1/4 inch) woody biomass is often required for bioenergy conversion technologies. This final sizing step is often done at the site of the bioenergy plant. Pelletizing is more energy and capital intensive than chipping but has been successful because of the resulting fuel quality. Pelletizers are most economical when operated as a centralized processing facility. Portable pelletizers are also available but their operating and capital costs are prohibitive unless the fuel is being used on-site. A pelletizer compresses the wood into 1/2 to 5/16 inch diameter by 1/2 to 1 inch long pellets. Resins and lignin in the wood serve to bind the pellet together to avoid its breaking down into sawdust. Pellets will have nearly twice the energy density and twice the bulk density of green woodchips with roughly 7,750 BTU per pound at 6% moisture (EPA 2009). Properly designed, operated, and maintained stoves burning these pellets can be expected to achieve a net combustion efficiency of about 83% (Vail 2007). Wood pellets also handle or flow more easily than chips. This is a very important feature for equipment that has an automatic fuel feeding system. Wood pellets are commonly bagged for use in home heating systems.

Torrefaction is a relatively new pretreatment application for woody biomass processing. This process is more energy and capital intensive than either chipping or pelletizing but has gained interest especially in co-firing applications. Torrefaction involves roasting wood chips in an oxygen free chamber at 140 to 350 ^{0}C to produce a powder that is then pelletized. An advantage of torrefaction is that it produces a fuel that has similar characteristics to coal, i.e. fuel density, grindability, and storage characteristics. It can be easily incorporated into existing coal fired power plants by mixing with the incoming coal stream.

Pyrolysis is used to produce a bio-oil from woody biomass as well as other biomass materials. Pyrolysis oil has a medium heating value. It can be transported long distances and processed at conventional oil refineries into a carbon-neutral liquid fuel or used to generate heat and electricity at small power generation plants (Bergman, 2008). Pyrolysis is described in more detail in the Conversion Technologies Assessment section of this report.

2.3.2 Moisture Content

Another deficiency of biomass fuels can be their moisture content. During the process of combustion, the water entrained in the biomass evaporates, this evaporation uses some of the heat generated by combustion. Thus there is heat loss associated with the moisture content of the biomass in addition to the heat losses usually associated with conventional fuels (principally the heat loss from hydrogen combustion and heat loss in exhaust gases). A pound of wood with a moisture content of fifty percent on a green-weight basis (in other words, half wood and half water), on a theoretical basis, contains about 4300 BTUs. When combusted, the total heat loss from evaporation, hydrogen combustion, and stack-gas heat losses combined, is about 1280 BTUs. Therefore, the resulting combustion efficiency is about seventy percent. The fuel cost component of energy generation costs as a function of the delivered price of woody biomass (with a higher heating value of 8600 BTUs per pound) is shown in Table 5 below.

Table 5. Fuel Cost ($/MMBTU)

MC		Woody Biomass Delivered Price ($/ton)					CE
gw	odw	10.00	20.00	30.00	40.00	50.00	(η)
0.00	0.00	0.73	1.45	2.18	2.90	3.63	80.08
9.09	10.00	0.81	1.62	2.44	3.25	4.06	78.74
16.67	20.00	0.90	1.80	2.70	3.61	4.51	77.41
23.08	30.00	0.99	1.99	2.98	3.97	4.97	76.08
28.57	40.00	1.09	2.18	3.27	4.36	5.45	74.74
33.33	50.00	1.19	2.38	3.56	4.75	5.94	73.40
37.50	60.00	1.29	2.58	3.87	5.16	6.45	72.07
41.18	70.00	1.40	2.79	4.19	5.59	6.99	70.73
44.44	80.00	1.51	3.02	4.52	6.03	7.54	69.39
47.37	90.00	1.62	3.25	4.87	6.49	8.11	68.08
50.00	100.00	1.74	3.49	5.23	6.97	8.71	66.72

MC is moisture content measured on a green-weight (gw) or an oven-dry-weight (odw) basis.

Note (2): CE (η) is combustion efficiency.

Woody Biomass Renewable Energy Production

Potential Annual Production and Heating Value

The left-most columns in Table 5 are equivalent moisture contents (MC), either on a green-weight (gw) basis or an oven-dry-weight (odw) basis. The right-most columns are combustion efficiencies (CE) associated with the various levels of moisture content. Fuel costs of woody biomass at different moisture contents may be interpolated using values in the table. Likewise, fuel costs for biomass with a higher delivery price may be calculated as multiples of the numbers in the table, for example, wood pellets at $160.00 per ton ($3.20 per forty-pound bag) with a moisture content of about five percent (green-weight basis), would represent a fuel cost of $12.41 per MMBTUs.

Quantification of Renewable Energy Production

Table 6 included in this section provides a summary of the potential amount of electricity, heat and transportation fuel that could be produced if all the woody biomass was utilized for the given conversion technology. Use of the wood feedstock for one technology will preclude its use for any other technology listed. Table 6 is meant to serve as a guide for what may be possible given the current quantities of woody biomass available and land for bioenergy crop production. A price/availability sensitivity analysis was beyond the scope of this study. It was assumed, in the table, that all woody biomass feedstock would be available for the bioenergy conversion process. It is important to recognize that there are competing uses for the wood. This factor must be taken into consideration before assuming how much woody biomass could be available for a given project.

Table 6. Woody Biomass Renewable Energy Production

	Unprocessed feedstock				Heat			
	Tons	% moisture	BTU/pound	Total Energy	Direct Combustion			
Source	(1000's)			(mmBTU)	mmBTU-50%(9)	mmG No.2 Fuel Oil Equivalent (11)	mmBTU-65%(10)	mmG No.2 Fuel Oil Equivalent (11)
Class I Feedstocks								
Bioenergy crops	890	45	4730	8,419,400	4,209,700	32.8	5,472,610	42.6
Forestry Residue	921	45	4730	8,712,660	4,356,330	33.9	5,663,229	44.1
Forest Processing	135	45	4730	1,277,100	638,550	5.0	830,115	6.5
Urban Wood	1,942	45	4730	18,371,320	9,185,660	71.5	11,941,358	93.0
Class I Subtotal	3,888			36,780,480	18,390,240	143.2	23,907,312	186.1
Class II Feedstocks								
C&D Waste	497	25	6880	6,838,720	3,419,360	26.6	4,445,168	34.6
Total	**4,385**			**43,619,200**	**21,809,600**	**169.8**	**28,352,480**	**220.7**

Woody Biomass Electricity Production Technologies

Potential Annual Production

Source	Power					
	Standalone (1)			Co-fire (2)		
	MWh	MW(5)	Tons Coal Equivalent	MWh	MW(5)	Tons Coal Equivalent
Class I Feedstocks						
Bioenergy crops	641,384	86.1	293,678	789,396	106	361,450
Forestry Residue	663,724	89.1	303,907	816,892	109.7	374,040
Forest Processing	97,289	13.1	44,547	119,740	16.1	54,827
Urban Wood	1,399,515	188	640,813	1,722,479	231.3	788,692
Class I Subtotal	2,801,912	376.3	1,282,946	3,448,507	463.1	1,579,010
Class II Feedstocks						
C&D Waste	520,969	70	238,542	641,193	86.1	293,591
Total	**3,322,881**	**446.3**	**1,521,488**	**4,089,699**	**549.2**	**1,872,600**

Source	Power					
	Small Gassification (3)			BIGCC (4)		
	MWh	MW(5)	Tons Coal Equivalent	MWh	MW(5)	Tons Coal Equivalent
Class I Feedstocks						
Bioenergy crops	518,041	69.6	237,202	912,739	122.6	417,927
Forestry Residue	536,085	72	245,464	944,531	126.9	432,484
Forest Processing	78,579	10.6	35,980	138,449	18.6	63,393
Urban Wood	1,130,377	151.8	517,579	1,991,617	267.5	911,926
Class I Subtotal	2,263,083	303.9	1,036,225	3,987,336	535.5	1,825,730
Class II Feedstocks						
C&D Waste	420,783	56.5	192,669	741,379	99.6	339,464
Total	**2,683,865**	**360.4**	**1,228,894**	**4,728,715**	**635.1**	**2,165,194**

Woody Biomass Transportation Fuel Production Technologies
Potential Annual Production

	Tranportation Fuel					
	Dilute Acid Hydrolysis (6)		Cellulosic Ethanol (7)		Gasification to Ethanol (8)	
Source	EtOH mmgal	mmGGE	EtOH mmgal	mmGGE	EtOH mmgal	mmGGE
Class I Feedstocks						
Bioenergy crops	26.92	18.30	31.82	21.63	24.48	16.64
Forestry Residue	27.86	18.94	32.93	22.38	25.33	17.22
Forest Processing	4.08	2.78	4.83	3.28	3.71	2.52
Urban Wood	58.75	39.94	69.43	47.20	53.41	36.30
Class I Subtotal	117.61	79.95	139.00	94.49	106.92	72.68
Class II Feedstocks						
C&D Waste	20.50	13.94	24.23	16.47	18.64	12.67
Total	**138.11**	**93.89**	**163.22**	**110.96**	**125.56**	**85.35**

(1) Assumes an efficiency of 26%, heat rate of 13,127 BTU/kWh

(2) Assumes an efficiency of 32%, heat rate of 10,666 BTU/kWh

(3) Assumes an efficiency of 21%, heat rate of 16,252 BTU/kWh

(4) Assumes an efficiency of 37%, heat rate of 9,224 BTU/kWh

(5) Assumes a capacity factor of 85%, operational 7446 hours per year

(6) Assumes a yield of 55 gallons of ethanol per dry ton of woody biomass, (range 40-65 gal)

(7) Assumes a yield of 65 gallons of ethanol per dry ton of woody biomass, (range 60-75 gal)

(8) Assumes a yield of 50 gallons of ethanol per dry ton of woody biomass, (range 40-60 gal)

(9) 50% net thermal conversion efficiency can be expected for a well-maintained wood-fired stove

(10) 65% net thermal conversion efficiency can be expected for a well-maintained steam boiler

(11) Used Lower Heating Value (LHV) of 128,450 btu/gallon for No. 2 Fuel Oil ("Properties of Fuels")

(12) Used average LHV of 23.3 mmBtu/ton coal and coal power plant efficiency of 32% ("Bioenergy Conversion Factors")

EtOH mmgal = ethanol, million gallons
mmGGE = million gallons - Gasoline Gallon Equivalent
mmBtu = Million Btu's
mmG= Million Gallons
MW = Megawatt
MWh = Megawatt hours

Summary

In order to determine the amount of wood-based biomass that could be sustainably produced in NJ and the resultant renewable energy production potential, an assessment of the major sources of wood was conducted. These included Class 1 type materials including; Forestry Residues, Primary and Secondary Forestry Products Industry Residues, Urban Forestry and Landscaping Residues, and Bioenergy Crops and Class 2 material which was from Construction and Demolition Waste sources. Once the maximum potential quantities of wood-based biomass was determined, the renewable energy production potential was determined based on the current efficiencies of the various appropriate conversion technologies. These findings are summarized in Table 7 below. It is important to note that these numbers represent an upward potential, a theoretical maximum of what might be produced, a ceiling to be used only for purposes of planning and are calculated by using the maximum yield potential and the most efficient conversion technology. The amounts of energy listed in the table assume all the biomass is utilized for that type of energy and would preclude its use for any other type of energy listed in the table. More detail is provided in the tables provided at the end of this section.

Table 7. Potential Maximum - Annual Bioenergy Production from Woody Biomass Sources

Type of Energy	Unit	Class 1	Class 2	Total
Electricity	Gigawatt Hours	3,987	741	4,728
Heat	Billion BTUs	23,907	4,445	28,352
Fuel	Mil. Gal. Ethanol	139.0	24.2	163.2

The amount of fossil fuels displaced is listed in the Table 8 below. As with the prior table, these numbers represent an upward potential, a theoretical maximum of what might be produced, a ceiling to be used only for purposes of planning and are calculated by using the maximum yield potential and the most efficient conversion technology. The most likely type of fossil fuel to be displaced, by energy type, was used in the calculations. The amounts of energy listed in the table assume all the biomass is utilized for that type of energy and would preclude its use for any other type of energy.

Table 8. Potential Maximum - Annual Amount of Fossil Fuels Displaced

Type of Energy	Unit	Class 1	Class 2	Total
Electricity	Thous. Tons Coal	1,826	339	2,165
Heat	Mil. Gal. #2 Oil	186.1	34.6	220.7
Fuel	Mil. Gal. Gasoline	94.5	16.5	111.0

The actual amount of woody biomass that is available for renewable energy production will be dependent on many variable factors. Biomass is a local resource. As such, local production depends on local conditions that are not accounted for in the information that was used to assess the overall potential. Reasons that the theoretical potential supply might not be recoverable include: (1) local, county, or state regulations, such as management restrictions; (2) good forestry practices, such as increased harvesting restrictions in wetlands; (3) economics of production, including market value and transportation costs; and (4) personal preference, such as a farmers and landowners wanting to manage agricultural and forest land for uses other than biomass production. As this analysis illustrates, NJ has many business development opportunities for wood-based bioenergy production. The information provided can be used as a resource for project developers looking to locate their business in NJ. In addition to the economic benefits of using NJ's woody biomass for energy production, there are many environmental benefits that could be realized from utilizing woody biomass as well.

Glossary

Biomass – Organic matter that is available on a renewable or recurring basis. It includes dedicated energy crops and trees, agricultural food and feed crop residues, aquatic plants, wood and wood residues, animal wastes, and other waste materials. It excludes old growth timber.
Black liquor – A liquid, lignin-rich byproduct that is produced from the processing of woody biomass. It is often produced at paper mills and can be used as a fuel in boilers.
Boles – Trunk of a tree
Btu – British thermal unit, a unit of energy equivalent to heating one pound of water one degree Fahrenheit.
Btu/kWh – British thermal units per kilowatt hour electricity. Amount of energy necessary to create one kilowatt hour of electricity
Btu/lb – British thermal units per pound of mass. It is a unit for the energy content of materials.
Cellulose – Organic polymer found in nature. It is the basic material in the structure of plants.
District heating – Heat is produced in a central location and is transported to local buildings via a piping system. It can utilize the waste heat of power plants.
Endothermic – Chemical reaction that requires the input of heat energy to take place.
Lignin – Naturally occurring organic polymer that is found in wood and is very resistant to chemical breakdown.
Megawatt – Unit of power that is equal to 1,000 kilowatts. Used to measure the amount of electrical output.
Megawatt-hour – Unit of electricity which is equal to the production of one megawatt for one hour
Urban forestry – Management of trees in densely populated areas.
USDA NASS – United States Department of Agriculture National Agricultural Statistic Service
Woody Biomass - Renewable organic matter that is derived from trees.

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Section 3: Identification and description of carbon sequestration projects that could serve as models for future projects in New Jersey

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Introduction

The objective of this section was to identify and describe existing projects suitable for replication in New Jersey for traditional and urban-community forest types. As discussed in the 'Results' section below, no 'turn-key' projects for replication were identified; however, there are existing projects to aid demonstration design. Regardless of site, the parameters of project duration, baseline determination, additionality, leakage, monitoring, verification, transparency and credibility can all be determined for projects using protocols from one of two registries: either the Northeast Regional Greenhouse Gas Initiative (RGGI) with the Maine Forest Service's Recommendations, or the Chicago Carbon Exchange (CCX).

Methodology

I. Met and discussed with colleagues
II. State-by-state web search
III. Survey of carbon sequestration web sites
    1. American Carbon Registry (ACR)
    2. Markit's Registry
    3. Climate Action Reserve's Registry (CAR)
    4. Northeast Regional Greenhouse Gas Initiative (RGGI): recommendations/protocols
    5. Chicago Carbon Exchange (CCX) Registry is proprietary
    6. Various coalition and private industry sites
IV. Discussions with U.S. Forest Service personnel, various state forestry personnel, and private industry personnel

Discussion

To date, most states have established various protocols for addressing greenhouse gas emissions and carbon sequestration. In 2002, California passed a law enabling forest landowners to register forestry activities for carbon credits, and over the past several years several agencies have been participating in "carbon-capture farming" demonstration projects in the Sacramento-San Joaquin Delta maximizing carbon sequestration and subsidence reversal. Similarly, Texas has developed a forest carbon sequestration program for private landowners (http://txforestservice.tamu.edu) and Georgia has established a registry and protocol (www.gacarbon.org, 2007) for landowners to register forestry activities for carbon credits. There are also many published studies of economic analysis and field procedures for measuring carbon sequestration in forests.

Approximately 52 projects in 24 different states (AL, AR, CA, GA, ID, IL, IN, KS, LA, MI, MN, MS, MT, NC, NJ, NY, RI, SC, SD, TX, UT, VT, WI, WY), with the most recorded in CA (16), are listed in Appendix 1. These projects are listed by region, forest and research focus, and can be broadly grouped into nine categories, ranging from forestry carbon trading, to investigating soil carbon under different forest types to research on what kinds of forest management activities can be truthfully credited with carbon reductions; but the majority of projects involve examining afforestation and reforestation, followed by some that examine forest management/improved forest management as related to carbon sequestration – with a few looking at a combination of both.

Appendix 2 lists forest carbon sequestration projects in the categories of private landowner, state lands, and urban-community lands. Not surprisingly, practically all of the projects found have been or are being implemented on either privately- or publicly-owned lands. Only three projects were identified in urban settings for monitoring the direct benefit of carbon sequestration from urban forest management. One was a 216-acre forested tract owned by the city of Syracuse, NY to be managed as sustainable forest and listed in Appendix 1. The remaining two are afforestation projects on less than five-acre tracts owned by two different municipalities in New Jersey, and have not yet formulated their procedures or parameters (Catania, 2010). While no other projects monitoring the direct benefit of carbon sequestration from urban forest management were found, several registries including the CCX, CAR and RGGI (with the Maine Forest Service RGGI Recommendations) provide protocols for urban forestry carbon sequestration projects.

Results

No 'turn-key' projects for replication were identified. Because carbon markets and the state of forest carbon protocols are in such flux, any existing project will have certain limitations and cannot be used as a full template. This would also probably be true even in a more stable environment, given normal ecological, social and market variation. There are, though, existing projects to aid demonstration design. At this stage, demonstration projects in New Jersey should be considered test cases to help determine what can be done in New Jersey, and even still may initially be limited. With that in mind, the following projects are noted.

Afforestation pilot projects on private land implemented by Winrock International in Shasta County, California under the **West Coast Regional Carbon Sequestration Project (WESTCARB)** are listed in Appendix 2 (Winrock International, 2007). It provides insight into the CAR protocol, and describes the procedure Winrock used to contact and interest private landowners. The **Bascom Pacific Forest Project** registered under the California Climate Action Registry (CAR) by the Pacific Forest Trust is an on-the-ground example of a forest management project that has been approved by a registry (The Pacific Forest Trust, 2009). It also provides insights into the CAR protocol, but it is large-scale at over 9,000 acres.

For demonstrations on privately-owned lands, the Georgia registry and protocol (www.gacarbon, 2007) and the Texas program (http://txforestservice.tamu.edu) have developed procedures for afforestation/reforestation and sustainable forest management projects. Each has adopted the CCX protocol, which includes methodology for establishing baselines, addressing leakage and project duration. Scale should not be a limiting issue at this stage for demonstration projects in New Jersey, given the average size of private and municipal ownerships in the state. Demonstration projects will help determine economic feasibility. Aggregation will be key for private landowners in New Jersey.

Georgia has established its own forest carbon sequestration registry. New Jersey may want to consider similar action. In Texas, the Texas Forest Service is the first state agency to become an authorized verifier for forestry offset projects by the CCX. This is probably not a consideration for New Jersey given the current economic climate in the state. Texas does, however, report 129 private landowners participating in afforestation through its program.

Project scale and project duration are both potential barriers for carbon sequestration projects on privately-owned lands in New Jersey. Twenty to twenty-five acres is the average size of forest ownership in New Jersey. Carbon trading projects are generally a minimum of 250 acres, with most much larger. A demonstration project on a small property can help determine feasibility, realizing that combining several small ownerships into a larger property ('aggregating') will most likely be the answer to the barrier of scale. The degree to which project duration is a barrier for privately-owned lands will depend on the registry protocol used. The Northeast RGGI protocol's call for projects to have a minimum 99-year duration would most likely only interest landowners who have already permanently deed-restricted their property through the State's farmland preservation program or a conservation easement. The much shorter duration protocols of the CCX and Georgia registries more closely correspond with the duration of written forest management plans and may be more appealing for landowners.

Recently-signed legislation creating The New Jersey Forest Stewardship Program may also potentially help address these potential barriers for carbon sequestration projects on privately-owned land. Among other things, the legislation will provide forest landowners the opportunity for farmland assessment (a lower property tax that is not based on 'highest and best use') without an annual income requirement, focusing management activities on other forest values, including carbon sequestration. Although the program does not become available until 1 January, 2010, and no rules, regulations, processes or guidelines have yet been developed for implementing it, there is the potential that it will encourage private forest landowners to include carbon sequestration in their forest management planning.

The **LaTour Forest Project** is a WESTCARB project utilizing CAR protocol for managing a state forest in California (Robards and Wickizer, 2009). Although not yet implemented, it provides a good example of the CAR procedures on state lands. When considering carbon sequestration projects on state lands, however, there is potential for barriers, particularly regarding easements, project duration, and, if in partnership with a non-state entity, how credits are distributed. **Georgia's Dixon Forest/Oglethorpe Power Project** is a good on-the-ground example of a carbon sequestration project on state lands

(Love, 2010; see Appendix 3). The State agencies that own and manage the State's forest lands must understandably be concerned about potential conflicts between public policies and protocols for carbon sequestration projects. These would include such things as public access, conflicting public uses and the legality of long-term restrictions. To avoid or overcome the aforementioned barriers, it would most likely be advisable for governmental agencies to seek counsel from their respective deputy attorney general's (DAG) office when planning forest carbon sequestration projects on state lands.

The search for carbon sequestration projects in urban areas confirmed the expectation stated in this project proposal, that there is little information on urban forest management targeted specifically for carbon sequestration. Therefore there is no discussion of projects for urban-community forest areas - community park-open space reserves and residential community zones. The potential for barriers and how to avoid them would be similar as those discussed for both privately-owned and state-owned lands.

Recommendations

New Jersey participates in the Northeast RGGI, therefore it may be desirable to utilize the RGGI (with the Maine Forest Service's RGGI Recommendations) protocol for any forest carbon demonstration projects, particularly on state-owned lands. Although RGGI initially only recognized afforestation offset projects, the Maine Forest Service's Recommendations have developed protocol drafts for avoided deforestation, active forest management, and biomass plantations as well as protocol for urban and community forestry projects. As a result, RGGI, like other registries such as the CCX, addresses the issues of project duration, baseline determination, additionality, leakage, monitoring, verification, transparency and credibility. The 99-year duration protocol, however, will be problematic for most landowners, except possibly for those who have already retired the development rights of their forests through the state's Farmland Preservation Program. The 99-year duration requirement could also prove a barrier to implementation of projects on state lands. Thus, the Georgia registry and protocol (www.gacarbon.org) using the CCX protocol may be more conducive for projects on privately-owned lands, and possibly state-owned lands, as well.

The Southern Group of State Foresters has recently completed a study and paper examining the key issues surrounding the development and application of forest-based offset projects in the southern region of the United States with recommendations for how these issues should be addressed in federal climate policy, should legislation be enacted (Fenderson, et al, 2009). The paper also includes a comparison of the current major registries and protocols for forest-based offset projects. Although focused on the South, it should, among other things, prove useful for designing projects in New Jersey.

Using the projects previously listed, and either RGGI or CCX protocol as mentioned above, there are opportunities to design and implement forest carbon sequestration demonstration projects on privately-owned lands, state lands and urban-community areas. The following are suggested:

I. Privately-owned lands
   A. For reforestation and/or sustainable forest management projects on properties over 1,000 acres both Lee Brothers in Burlington County and Lenape Farms in Atlantic County have forest management plans in place and are members of the American Tree Farm System.
   B. For projects on more typically-sized properties, the New Jersey Forestry Association's members can provide volunteers with forest management plans in place, and/or that are members of the New Jersey Stewardship Program and the American Tree Farm System.

II. State-owned lands or state-private partnerships
   A. State parks and forests and state fish and wildlife lands offer opportunities for reforestation, re-establishment of Atlantic white-cedar and forest management projects. However, the requirement of forest management plans, easement and project duration protocols may provide barriers for implementing carbon sequestration projects on state lands.
   B. The Berkeley Triangle Project in Ocean County and the Parker Preserve in Burlington County are state-private partnerships that may offer opportunities for demonstration projects where potential protocol barriers may not be as problematic.

III. Urban-community areas
   A. Although no urban forestry projects were identified, there are viable opportunities. Many of New Jersey's municipalities participate in the 'Tree City USA' program and have management plans for their urban forest resource, thus opportunities for reforestation and forest management projects.
   B. Several northeastern New Jersey municipalities recently were forced by Asian long-horned beetle infestation to remove their entire urban forest resource, offering excellent opportunity to monitor direct urban forest carbon sequestration.
   C. Liberty State Park is a heavily visited urban park in Hudson County. Although likely subject to the same potential protocol barriers previously mentioned for other state lands, it offers opportunity for sequestration projects.

Summary

With increasing interest and activity in 'carbon offsets' and 'cap-and-trade' programs over the past several years, there has also been a steadily increasing interest in the area of forest-based carbon sequestration and forest-based carbon offset programs. The recent years of economic downturn have slowed this increase somewhat, but substantial interest remains.

Despite the many forest carbon sequestration projects either currently being implemented, underway or contemplated, however, it is challenging to locate detailed and/or replicable projects. For instance, Forecon, Inc., a private aggregator operating

throughout the Northeast developing forest-based carbon offset programs with an interest in focusing on privately-owned lands, felt its projects are proprietary and would not divulge or discuss them (Carlson, 2010). On the other hand, The Nature Conservancy in Pennsylvania with Blue Source, a carbon sequestration company, launched 'Working Woodlands' on 3 December, 2009, an innovative program intended to encourage long-term forest management on private lands that incorporates carbon revenues into management (The Nature Conservancy in Pennsylvania, 2010). The program is specific for Pennsylvania, but may eventually prove a model or be modified and adapted for New Jersey.

Without a totally replicable project, any one or combination of the potential sites for carbon sequestration demonstrations previously listed can be used with the sequestration projects mentioned as guides to design projects on private and state lands. The Georgia Carbon Registry will be particularly helpful for both private and state lands. As expected, projects for urban-community forest types will need to be developed from concept. The forestry protocols of either RGGI or CCX will guide project duration, baseline determination, additionality, leakage, monitoring, verification, transparency and credibility.

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Appendix 1

Forest Based Carbon Sequestration Projects

State	Project	Project type	Acres	Species	Contact or Manager

Note: See page 14 for definitions of acronyms

	Private Lands				
AR	**Bayou Bartholomew Carbon Offset Project**, Lower Mississippi Alluvial Valley, near Mitchellville, AR	Reforestation on private marginal farmland	400	sweet gum, bald cypress, tupelo, green ash and oak species—willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Ducks Unlimited, and a private landowner
AR	**White River Carbon Offset Project,** Lower Mississippi Alluvial Valley in NE AR, near Newport, and close to the White River NWR	Bottomland hardwood forest restoration on **private marginal farmland**	1,000	sweet gum, bald cypress, tupelo, green ash and oak species—willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Central Arkansas Resource Conservation and Development Council (project developer), the USDA Natural Resources Conservation Service and a **private landowner**
CA	WESTCARB – Siskyou and Shasta Counties. The Pacific Forest Trust\Bascom, Demonstration of Conservation-Based Forest Management to Sequester Carbon on the Bear Creek and McCloud River Blocks owned by Bascom Pacific Forest. Report by Winrock International	Carbon project to: **1.** Demonstrate how baselines and conservation-based management activities in a productive forestland site would be interpreted on this site if a CO2 emissions reduction project were undertaken under the California Climate Action Registry Forest Project Protocol (Version 2.1) **2.** Identify specific management activities that would create carbon reductions on this site **3.** Evaluate the costs and benefits for the purpose of registering forest carbon stock changes with the Climate Action Reserve ("Reserve" or "CAR")	9,200	mostly coniferous species	Winrock International is the contractor for the report to the California Energy Commission/ CIEE for the U.S. Department of Energy. The Pacific Forest Trust is a Cooperator

State	Project	Project type	Acres	Species	Contact or Manager
CA	WESTCARB Shasta County terrestrial Project. **Phase 1** This project is one of seven US Department of Energy regional partnerships working to evaluate the potential of carbon capture, storage and sequestration options in different regions of the country and determine the most suitable technologies, regulations, and infrastructure needs for sequestration as a climate change mitigation strategy. **Phase 2** to follow will include 70 consortium members to study effects of afforestation in Lake County, Oregon, with fast growing species including hybrid poplar. Based on the results of the Shasta and Lake County pilot projects Winrock will identify pilot project sites in Washington and Arizona	**Phase 1** Afforestation, fuel management/biomass energy, and forest management	**Phase 1** 336 acres planted to date. The acreage of fuel mgt, biomass and forest mgt. projects TBA	**Phase 1** mixed conifers	**Phase 1** Winrock International w/ US Dept of Energy and a consortium of State, Shasta Resource Conservation District, industry and private landowners
LA	**Walsh Lake Carbon Offset Project,** Lower Mississippi Alluvial Valley, in east central Louisiana near Larto, LA	Reestablishes bottomland hardwood forest on private land, between the Dewey Wills WMA and Lake Ophelia NWR	500	sweet gum, bald cypress, persimmon, native pecan, mayhaw, honey locust, sycamore, hackberry, winged elm, cedar elm, green ash and oak species—water, willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Old South Woodlands LLC (project developer, tree planting), Environmental Synergy Inc., a **private landowner,** and Ducks Unlimited
LA	**Lake Carbon Offset Project**, Lower Mississippi Alluvial Valley, in Central LA near Alexandria	Reestablish bottomland hardwood forests on 909 acres of **private and public land**	909	sweet gum, bald cypress, tupelo, green ash and oak species—willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Conservation Fund, a private landowner, Environmental Synergy Inc., and the USFWS
MS	**Southfresh Farms Carbon Offset Project**, Lower Mississippi Alluvial Valley, in Central, MS	Bottomland hardwood forest restoration on private land previously used for catfish farming	200	sweet gum, bald cypress, tupelo, green ash and oak species—willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Environmental Synergy Inc., and a **private landowner**

State	Project	Project type	Acres	Species	Contact or Manager
TX	***Carbon Credits for Landowners*** is a Texas Extension Service publication tells how landowners can potentially realize income from sale of carbon credits and the pitfalls that can be encountered. **Note:** Texas FS is the only State Forest Service authorized by CCX to verify forestry offset projects for landowners seeking to sell their trees' carbon credits on the open market.	Texas landowners have received solicitations from carbon brokers to sell their "carbon credits." But what does it mean? Is it a good deal? And does it truly provide an opportunity to generate additional income? The publication helps answer these questions. The Texas Forest Service verifies landowner carbon offset projects			Texas Extension Service at Texas A & M and Texas Forest Service
	State Lands				
CA	The carbon certification project is located in the La Tour Demonstration State Forest in the southern Cascade Mountains in Shasta County, northeast of the city of Redding, CA. California Division of Forestry (CDF) is conducting the study to evaluate the protocols and develop analysis tools for foresters for use if and when a cap and trade program is in place in the state.	Management has the potential to dramatically change carbon sequestration rates in the project area	300	30 year-old burned-over mixed conifer and ponderosa pine forestland and brush fields surrounded by true fir	State of California, California Division of Forestry
GA	**The Georgia Forestry Commission (GFC) and Oglethorpe Power Corporation** have formed a first-of-its-kind partnership in the state to reforest as much as 500 acres of hardwood forestland burned in wildfires near the Okefenokee Swamp in 2007. Dixon Memorial State Forest located in Ware and Brantley Counties.	As part of its agreement with the GFC, Oglethorpe Power will be able to receive credit for the carbon dioxide captured by the replanted trees as future climate change regulations unfold. Oglethorpe Power will have title to the carbon dioxide removed from the air by the trees for the first 25 years, then will share those rights with the state for an additional 50 years.	500	bottomland hardwoods and cypress	Georgia Forestry Commission (GFC) and Oglethorpe Power Corporation
GA	***Guiding Principles for a Practical and Sustainable Approach to Forest Carbon Sequestration Projects in the Southern United States.*** An examination of the key issues about development and application of forest based carbon offset projects in the southern region of the U.S.	Provides recommendations for the Southern Group of State Foresters on how carbon offset issues should be addressed in federal climate policy should legislation be enacted			Services, Utilization and Marketing Task Force, Southern Group of State Foresters
LA	**Bayou Pierre Carbon Offset Project**, Lower Mississippi Alluvial Valley, near Natchitoches, LA.	Reforestation on State land	500	sweet gum, bald cypress, tupelo, green ash and oak species—willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Nature Conservancy, Environmental Synergy Inc. and the Louisiana Department of Wildlife and Fisheries

State	Project	Project type	Acres	Species	Contact or Manager
TX	**Texas Parks and Wildlife Department (TPWD)** Old Sabine Bottom Wildlife Management Area	Reforestation Restoring Biodiversity	600	162,000 native trees in diverse bottomland hardwood system, water oaks, willow oaks, and native pecan	State of Texas, Conservation Fund, Reliant Energy, and Environmental Synergy
	Urban and Community Lands				
NY	Rand Tract, Owned by City of Syracuse, NY	Manage 2nd growth forest through Conservation Easement and protect from development	216		
NJ	Town of Woodbridge, Pin Oak Afforestation Project, Middlesex Co., NJ	Afforestation of headwaters of Woodbridge river	3	pin oak	Conservation Resources, Elizabethtown Gas and Woodbridge Township
NJ	D&R Greenway Trust, St. Michael's Afforestation Project	Afforestation at St. Michael's Preserve	1	trees and shrubs	Conservation Resources, Elizabethtown Gas and D&R Greenway Land Trust
	Federal – USDA FS National Forests				
CA	**Mendocino NF**-Alder Springs. Research project to determine the carbon benefits associated with hazardous fuels thinnings, including how to measure the amount of greenhouse gases emitted by wildfires	Research on what kinds of projects can truthfully be credited with carbon reductions. Thinnings to be chipped and sent to a biomass energy plant	3,662	brush (scrub oak, manzanita, and chaparral), pine, and mixed-conifer vegetation	Mendocino NF, PSW Research Station, Winrock, Wheelabrator Energy Co. and State CA
CA	**Plumas NF**- a Carbon Sequestration Demonstration Unit, in the 2007 Moonlight Fire area Funded through Carbon Capital Fund	Reforestation to demonstrate how forest management may be used as one part of a national climate change mitigation strategy through reforestation by planting 117,000 seedlings estimated to sequester 50,000 tonnes of carbon	561	ponderosa pine, Jeffrey pine, Douglas- fir, incense cedar, sugar pine, white fir and red fir	NFF thru the CCF, Plumas NF, and Ruby Pipelines of the El Paso Corporation
CA	**San Bernardino NF** wildfire area – headwaters of San Jacinto Basin. Funded through Carbon Capital Fund	Reforestation— seedlings grown for 2009 planting season		Jeffery, ponderosa, lodgepole, sugar & Coulter pines; incense cedar and white fir	NFF thru the CCF and USFS
CA	**Plumas NF** Feather River Watershed Funded through Carbon Capital Fund	Reforestation— seedlings grown for 2009 planting season		mix of Douglas-fir, ponderosa pine, sugar pine, incense cedar and white fir	NFF thru the CCF and USFS
ID	**Payette NF** Reforest area damaged by a June 2006 tornado near Bear, ID. Funded through Carbon	Reforestation	1,400	ponderosa pine, Douglas-fir, western larch, & Engelmann	NFF, CCF & USFS

	Capital Fund			spruce	
State	**Project**	**Project type**	**Acres**	**Species**	**Contact or Manager**
MT SD	**Custer NF,** Reforest area burned by the Kraft Springs Fire Funded through Carbon Capital Fund	Reforestation— forest inventory crews collected baseline data to determine initial carbon levels for the project area. Planting crews followed in 2008	500	ponderosa pine	NFF thru the CCF & USFS
NC	USDA Forest Service The Bent Creek Experimental Forest is within the **Pisgah NF** near Asheville, North Carolina. studies, some established more than 80 years ago, are still yielding valuable information	Today some of those studies are being used to address current issues such as climate change mitigation through carbon sequestration			
SC	USDA FS Southern Research Station Savannah River Site National Environmental Research	What can the power industry expect from terrestrial carbon sinks in terms of capacities? Project: The efficacy of incorporating forest slash below ground in loblolly plantation site prep to improve soil quality and carbon sequestration		loblolly pine	USDA FS Southern Research Station Ashville, NC
	Federal — Indian Reservations				
ID	Nez Perce Reservation	Idaho's first forestry carbon trade			NCOC & CCX
	Federal — USFWS National Wildlife Refuges				
KS	Restoring a forest legacy at Marias des Cygnus NWR, 70 miles so. of Kansas City, KS	Afforestation and reforestation of degraded farmland	1,918	hardwood forest: native oak and hickory	USFWS & Conservation Foundation
LA	Tensas River NWR in Louisiana's Lower Mississippi River Valley *The Tensas River National Wildlife Refuge Reforestation Project* Voluntary	Reforestation to restore forest clearcut in 1930s and 40s for agriculture crops grown until 2003	9,000 with potential of 2,300 more	21 tree species of oaks, green ash, bald cypress, sweet pecan	USFWS and Trust for Public Lands
LA	Restoring a Legacy at Red River NWR, Natchitoches Parish in northern LA. Voluntary OTC Registry: Climate Action Reserve	Raising donations for afforestation and reforestation on marginal crop land to native bottomland hardwood forest	2,920	Hardwood forest	The Conservation Fund, Go Carbon Zero, USFWS and others
LA	**Bayou Pierre II Carbon Offset Project**, Lower Mississippi Alluvial Valley, near Natchitoches, LA	Bottomland hardwood forest restoration on Federal Land	200	sweet gum, bald cypress, tupelo, green ash, oak species— willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Nature Conservancy, Environmental Synergy Inc., and the USFWS
LA	**Spanish Lake Carbon Offset Project**, Lower Mississippi Alluvial Valley, in Central LA near Alexandria.	Reestablish bottomland hardwood forests on 909 acres of **private and public land**	909	sweet gum, bald cypress, tupelo, green ash and oak species— willow, overcup, cherrybark and nuttall	PowerTree Carbon LCC, Conservation Fund, Environmental Synergy Inc., & USFWS

State	Project	Project type	Acres	Species	Contact or Manager
	Universities				
MS	**Mississippi State University** Forest and Wildlife Research Center *Forest carbon Management: Opportunities and Protection* Site John C. Stennis Space Center	Potential for improving carbon sequestration at the stand, local, state, and regional levels via afforestation and reforestation of appropriate lands or the intensification of forest practices on industrial or non-industrial forest lands		biomass fuels	CSREES CRIS Number MISZ-069210
RI	**University of Rhode Island** Natural Resource Sciences *Carbon Sequestration and flux in Forests at the Landscape Scale* Sites: Across Southern New England	Are deciduous or coniferous forests more likely to store more carbon in the soil?		Merrimac, Windsor and Sudbury soils	CSREES CRIS Number 0198246
UT	**Utah State University** Wildland Resources *Nutrient Dynamics in Wildland Ecosystems*T.W. Daniel Experimental Forest and in the Upper Frost Canyon at the Desert Land and Livestock Ranch	Do soil organic carbon (SOC) pools differ significantly under forest and rangeland ecosystems typical of Utah? Is regional climate the major driver of SOC storage?		aspen and coniferous forests of the West	CSREES CRIS Number UTA00703
VT	**University of Vermont** *Quantifying Carbon Pools, Sequestration Potential, and reactivity in Vermont Soils* On six established plots in each of five watersheds in Vermont	To estimate soil carbon pools in Vermont soils and investigate the relationship between tree species and carbon in Vermont forest soils		sugar maple, yellow birch, beech and conifers	CSREES CRIS Number VT-H01505
WY	**University of Wyoming** Renewable resources *Forest Management Effects on Ecosystem Carbon Dynamics* Sites: Black Hills, New Castle, WY and Medicine Bow NF, Laramie, WY	To demonstrate biophysical potential and economic costs of creating carbon credits from different management: control even aged, uneven aged and heavy harvest in ponderosa pine and control and managed regeneration after clearcut in lodgepole pine		ponderosa pine and lodgepole pine	Partially funded by Wyoming Carbon Sequestration Advisory Group
	Climate Action Reserve Listings				
CA	Big River/Salmon Creek, Mendocino Co., CA Voluntary OTC Registry: Climate Action Reserve	Restore and manage depleted redwood/Douglas-fir forest	16,701	temperate rainforest	The Conservation Fund, ERT, Winrock, **CA State Water Board** & others Forest Carbon Project Inventory
CA	Garcia River Forest, The first **non-profit** working forest in CA, Mendocino Co., CA Voluntary OTC Registry: Climate Action Reserve	Improved forest management. Seeks to balance ecological protection and restoration needs of depleted industrial timberland with the economic imperatives of ownership	23,791	temperate rainforest	The Conservation Fund & The Nature Conservancy
CA	Lompico Headwaters Forest Carbon Project, Lompico, Santa Cruz Co.	Afforestation and reforestation		hardwood forest	
CA	Love Creek Working Forest, Arnold, CA.	Improved forest management, afforestation and reforestation	1,020	hardwood forest	Love Creek Forest,

	Permanent conservation easement Voluntary OTC Registry: Climate Action Reserve				Forest Carbon Project Inventory
State	**Project**	**Project type**	**Acres**	**Species**	**Contact or Manager**
CA	McCloud River **Pondosa Forest LLC**. McCloud, CA Voluntary OTC Registry: Climate Action Reserve	Improved forest management, afforestation and reforestation	22,734	hardwood forest	Pondosa Forest, Forest Carbon Project Inventory
CA	**Phillips Family Tree Farm** Shasta County, CA Voluntary OTC Registry: Climate Action Reserve	Improved forest management, afforestation and reforestation	2,273	hardwood forest	Phillips Family Trust, Forest Carbon Project Inventory
CA	**RPH Ranch** Comptche area, Mendocino Co. , CA Voluntary OTC Registry: Climate Action Reserve	Improved forest management	296	hardwood forest, all old growth trees above 48" DBH to be retained Coho salmon and steelhead watershed	Forest Carbon Project Inventory
CA	**Van Eck Forest Project** to reduce 500,000 tons of CO2 over 100 years. First Project registered and certified under California's Forest Protocols. Voluntary OTC Registry: CAR	Improved forest management. Sustainable timber harvest providing the building industry and consumers with eco-friendly wood products and local community with dependable jobs	2,200	redwood forest, temperate rainforest	Owned by Fred M. Van Eck Forest Foundation, Managed by Pacific Forest Trust, Forest Carbon Project Inventory
CA	**Waddle Ranch**, Truckee, CA Owned by Truckee-Tahoe Airport, Truckee Donner Land Trust, Placer County and California Fish and Game. Voluntary OTC Registry: CAR	Fire hazard reduction and Improved forest management	3,662	temperate coniferous forest, scenic viewshed near Lake Tahoe	Managed by Truckee-Tahoe Airport. Forest Carbon Project Inventory
	Delta Carbon – Forest Carbon Inventory Projects				
MI	Delta Carbon MF XFO Pool MFO Registry: CXX (To be 2009)	Afforestation and reforestation	16,949	hardwood forest	Delta P2/C2 Center
IL	Delta Carbon XFO Pool 1 Registry: CXX	Afforestation and reforestation	2,980	hardwood forest	Delta P2/C2 Center
AL, IL	Delta Carbon XFO Pool 2 Registry: CXX (To be 2008-2010)	Afforestation and reforestation	5,567	hardwood forest	Delta P2/C2 Center
AR	Delta Carbon XFO Pool 3 Registry: CXX (2009)	Afforestation and reforestation	8,881	hardwood forest	Delta P2/C2 Center
IL, IN, LA, MI, MN	Delta Carbon XFO Pool 4 Registry: CXX(To be 2009)	Afforestation and reforestation	4,354	hardwood forest	Delta P2/C2 Center
IL, MI, AR	Delta Carbon XFO Pool 5 Registry: CXX (2009)	Afforestation and reforestation	1,730	hardwood forest	Delta P2/C2 Center

Acronyms

CCF = Carbon Capital Fund **CAR** = Climate Action Reserve	**USDA FS** or **USFS** = United States Department of Agriculture Forest Service **NF** = National Forest **NFF** = National Forest Foundation	**Voluntary OTC** = "Over-the-Counter" Voluntary Carbon Markets
NFF = National Forest Foundation	**NWR** = National Wildlife Refuge	**CSREES** = Cooperative State Research Education and Extension Service
CCX = Chicago Carbon Exchange	NCOC = National Carbon Offset Coalition	**CRIS** = Current Research Information Number
US FWS = United States Fish and Wildlife Service	**PSW** = Pacific Southwest Forest Experiment Station **PNW** = Pacific Northwest Forest Experiment Station	**USDA NRCS** = United States Department of Agriculture Natural Resources Conservation Service
USDI BLM = United States Department of Interior Bureau of Land Management	**USDI NPS** = United States Department of Interior National Park Service	**USDI NRA** = United States Department of Interior National Recreation Area

Appendix 2

Forest Based Carbon Sequestration Projects of Interest for New Jersey

See Appendix 1 for project details

Private Lands

California	Bascom forest demonstration of conservation-based forest management to sequester carbon on Bascom land in cooperation with Pacific Forest Trust.
California	WESTCARB Shasta County Terrestrial Project. Private and government owners afforestation, fuel management/biomass energy, and forest management.
Georgia	Registry and protocol procedure established for carbon sequestration projects**.**
Texas	Has developed a program to encourage carbon sequestration by forest landowners (includes publications such as '*Carbon Credits for Landowners*' that informs landowners how to potentially realize income from sale of carbon credits and pitfalls that can be encountered); Texas Forest Service is the only State FS to be a CCX verifier.

State Lands

California	LaTour Demonstration Site. A study to develop analysis tools for foresters to use if and when a cap and trade program is in place.
Georgia	Georgia Forest Commission and Oglethorpe Power form partnership where power company reforests burned area on Dixon State Forest and receives carbon credits.

Urban and Community Lands

(Two very small projects)

New Jersey	Town of Woodbridge. Afforestation of the headwaters of Woodbridge River.
New Jersey	D&R Greenway. Afforestation at St. Michael's Preserve.

APPENDIX 3

Georgia Forest Commission and Oglethorpe Power
Carbon Sequestration Project Partnership

Project Name: The Dixon Forest/Oglethorpe Power Carbon Project.

Type of Project: Reforestation/restoration.

Project Objective: Restore wildfire devastated bottomland hardwood and cypress forests and reduce green house gases in the atmosphere through forest carbon sequestration.

Size of the Project: Approximately 384 acres located on 24 noncontiguous tracts all within the Dixon Memorial State Forest.

Registry for the Project: Oglethorpe Power is considering the Georgia Carbon Sequestration Registry and most likely one of the national carbon offset registries.

Project Duration: 75 years total. Oglethorpe Power will receive 100% of project offset credits for the first 25 years from the date that a mandatory federal emissions cap takes effect. Beginning 25 years after the date of the mandatory cap until the end of the 75 years, Oglethorpe Power and the state of Georgia will share on a 50/50 basis any carbon offset credits accumulated during the remaining project time period.

Baseline: The baseline for this project is a business as usual approach which assumes "hands off" or passive management on the part of the GFC for the lands in question (i.e., natural succession). The business as usual approach on the part of GFC is such that the project area forests could not be restored without external funding mainly because of budget constraints.

Problems/Barriers: The main problem/barrier to project implementation was the challenge of legally encumbering state owned land for a 75 year period. The Georgia State Property Commission and the Georgia State Attorney General Office decided that a conservation easement would be needed in order to go forth with the project. This brought on the next barrier in the fact that conservation easements in Georgia require an actual survey be done on all easement acreage. Surveying the project's 24 scattered tracts would have placed a much too onerous financial burden on Oglethorpe Power and would have most likely been a deal breaker. This problem was solved and the project saved when the attorney general office ruled that GPS points around the project perimeter as well as a permanent iron pin to mark the beginning of each tract would be legally sufficient in lieu of an actual survey.

Section 4: Potential Income from the Sale of Carbon Offsets and Class I Renewable Energy Certificates

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Potential Income from the Sale of Carbon Offsets in Regional and National Markets

The sale of CO_2 offsets generated from carbon sequestration forestry projects in regional and national markets represents a significant potential revenue stream through the sale of the offsets. An offset represents the reduction of one ton of CO_2 from a specified mechanism. The current market is fairly limited with regards to carbon sequestration projects, but there is the potential for a large number of projects to be accepted by a number of markets in the future. The current and potential markets are described in the subsequent sections with a projection of potential income that can be realized from these markets.

Before describing the markets and estimated market prices for offsets, it is important to note the high level of uncertainty surrounding estimating future revenue streams. First, there is substantial policy uncertainty at the international, national, and regional level. At this point, it is not clear if and when the U.S. will adopt a national greenhouse gas policy and if so, to what extent that policy will allow for the sale of offsets and what those offset prices will be. Second, there is extensive economic uncertainty. The price of offsets depends on numerous factors, including, among many other factors, the level of economic activity and fuel prices. It is not clear when the current economic recession will end and when it does, what the future economic growth levels will be. Third, even if there were more policy and economic certainty than exists today, there is uncertainty in the technological advances and therefore costs and capabilities of strategies and measures to reduce or mitigate greenhouse gas emissions. Thus, the estimates of future revenues due to the selling of offsets presented below must be viewed as an estimate that is subject to much uncertainty.

1.1 Possible Carbon Offset Markets to Participate in

1.1.1Regional Greenhouse Gas Initiative (RGGI)

RGGI is a cap-and-trade program for ten northeastern and Mid-Atlantic states (Connecticut, Delaware, Maine, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Rhode Island, and Vermont) that caps electric power plants' CO_2 emissions. A regional cap is set, with each state within the region issuing CO_2 allowances to its portion of the regional cap. Each allowance represents a permit to emit one tone of CO_2. The goal of the cap is to stabilize emissions between 2009-2014 and then reduce the cap by 2.5 percent each year between 2015-2018.[1] The initial auction took place on September 25, 2008, with subsequent auctions held quarterly.

Electric power generators must hold allowances equal to their CO_2 emissions, with all fossil fuel-fired electric power plants 25 megawatts or greater in size regulated by RGGI. If companies are unable to meet their compliance obligations or would like to further reduce CO_2 emissions, they can purchase offsets, which act to reduce the cap. There are currently five RGGI eligible offset project categories: landfill methane capture and destruction, reduction in emissions of sulfur hexafluoride in the electric power industry, sequestration of carbon due to afforestation, reduction or avoidance of CO_2 emissions from natural gas, oil, or propane end-use combustion due to end-use energy efficiency in the building sector, and avoided methane emissions from agricultural manure management operations.

Currently, the only carbon sequestration offset project eligible through RGGI is afforestation. Afforestation offset projects sequester carbon through the conversion of land from a non-forested to forested condition. Carbon sequestration is determined using a base-year approach, where the amount of carbon sequestered is measured relative to the base-year carbon measurement or previous reporting period carbon measurement.[1] In order to qualify the offset project must occur on land that has been in an un-forested state for at least 10 years prior to the afforestation and the land must be managed with environmentally sustainable forest practices.[2] It is the belief of the New Jersey Department of Environmental Projection, though, that the carbon sequestration offsets of RGGI will be greatly expanded in the near future and more forest projects will be eligible.[3]

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[1] Regional Greenhouse Gas Initiative. *The Regional Greenhouse Gas Initiative Is…* Available at http://www.rggi.org/docs/RGGI_Executive%20Summary_4.22.09.pdf. Accessed on September 20, 2009.

[2] Regional Greenhouse Gas Initiative. *Afforestation.* Available at http://www.rggi.org/market/offsets/categories/afforestation

[3] Topic discussed at a meeting on September 29, 2009 between the NJ DEP and the Rutgers Research Team.

1.1.2 The Proposed American Clean Energy and Security Act of 2009 (CESA)

The American Clean Energy and Security Act of 2009 (Waxman-Markey discussion draft) was introduced into the US House of Representatives in May 2009 and was passed by the House in June 2009 (it's companion bill, the Clean Energy Jobs and American Power Act of 2009, was introduced in the Senate on September 30, 2009 and is currently awaiting a Senate vote). The legislation is a comprehensive energy bill that includes sections on clean energy, energy efficiency, global warming, and transitioning. The global warming section establishes a market-based program for reduction global warming pollution from electric utilities, oil companies, large industrial sources, and other covered entities that collectively are responsible for 85% of US global warming emissions.[4] The long-term goals of the program are that aggregate emission are 20% below 2005 levels by 2020, 42% below 2005 levels by 2030, and 83% below 2005 levels in 2050.[4] Similar to the RGGI program, covered entities must have allowances for each ton of pollution emitted into the atmosphere.

Entities are allowed to obtain offsets to increase their emissions above their allowances. The total quantity of offsets allowed in any year cannot exceed 2 billion tons, split evenly between domestic and international offsets. Specific offset eligibility and project types will be established by an independent Offsets Integrity Advisory Board composed of scientists and others with relevant experience.[5]

1.2 Potential Revenue from Carbon Offset Markets

Participation in carbon offset markets can be quite lucrative and represent a significant potential revenue stream for participants in the market. The analysis provided assumes the RGGI market will be in place between 2010-2014 and the CESA market will be operational starting in the year 2015. It is assumed that a national market will supersede RGGI, so the RGGI market will cease to exist with the introduction of CESA. Offset forecast prices range from approximately $3 per allowance in 2009 in the RGGI market to up to $185 in the CESA market in 2050 (in 2050 dollars). Actual RGGI auction market prices were used through the year 2012 and escalated with inflation for subsequent years.[6] The CESA allowance price forecast was taken from analysis preformed by the US Environmental Protection Agency.[7] The CO_2 allowance forecast for selected years between 2010-2050 is below in Table 1.

[4] US House of Representatives. *Discussion Draft Summary of the American Clean Energy and Security Act of 2009*. Available at http://energycommerce.house.gov/Press_111/20090331/acesa_summary.pdf.

[5] US House of Representatives. *Section-by-Section Discussion of the American Clean Energy and Security Act of 2009*. Available at http://energycommerce.house.gov/Press_111/20090331/acesa_sectionsummary.pdf.

[6] Regional Greenhouse Gas Initiative, *RGGI Auction Results*, December 2009. Available at http://www.rggi.org/co2-auctions/results.

[7] US Environmental Protection Agency. *EPA Analysis of the American Clean Energy and Security Act of 2009 H.R. 2454 in the 111th Congress*. June 23, 2009. Available at http://epa.gov/climatechange/economics/pdfs/HR2454_Analysis.pdf.

Table 1: CO_2 Allowance Forecast for 2010-2050 (All Values in Nominal $)

	Carbon Credit Prices ($/Ton)
2009	3.08
2010	3.28
2011	3.28
2012	3.23
2013	3.31
2014	3.39
2015	16.11
2016	17.34
2017	18.61
2018	19.97
2019	21.37
2020	22.83
2025	34.51
2030	48.57
2035	70.38
2040	95.57
2045	137.63
2050	185.33

Note: This is a forecast of CO_2 Allowance Prices with RGGI prices from 2010-2015 and CESA prices from 2016-2050

It is estimated by Rutgers' Walton Center for Remote Sensing and Spatial Analysis that there are approximately 655,630 hectares of rural (i.e. non-urban) forest land in New Jersey, which is taken from Section I of this report. As part of Section I of this report the yearly total carbon flux, which is the yearly incremental carbon sequestered by New Jersey's forests, was calculated by the Walton Center. The yearly incremental carbon flux is for the years 2010-2050 is presented in Table 2 below.

Table 2: Yearly Incremental Carbon Flux Sequestered in New Jersey's Forests

	Total Carbon Flux (Tons)	Carbon Flux per Hectare (Tons)
2010	259,968	0.40
2011	324,237	0.49
2012	448,377	0.68
2013	576,857	0.88
2014	752,863	1.15
2015	913,527	1.39
2016	1,128,001	1.72
2017	1,406,405	2.15
2018	1,522,276	2.32
2019	1,692,216	2.58
2020	1,848,329	2.82
2025	2,253,335	3.44
2030	2,417,399	3.69
2035	2,288,441	3.49
2040	1,953,976	2.98
2045	1,803,064	2.75
2050	1,625,043	2.48

Of this forest land, it is unknown the specific amount of land that will qualify for carbon sequestration both in the RGGI market and in the CESA market. Table 3 below shows potential income from the sale of offset allowances in six different sensitivity analysis scenarios when a national CO_2 program is in place. The six scenarios are if a single hectare is utilized, if 1% of the hectares are utilized, if 5% of the hectares are utilized, if 10% of the hectares are utilized, if 50% of the hectares are utilized, and if

100% of the hectares are utilized. All values are the net present value of the sale of the offsets in two time scenarios, 2010 through 2050 (the length of the forecast from the US EPA) and 2010 through 2109 (a 100 year timeframe).[8] The net present value ranges from $1,256 to $3,327 depending on the discount rate for a single hectare of land through 2050 and ranges from $1,503 to $5,131 depending on the discount rate for a single hectare of land through 2109. If all available forest land is able to be utilized for carbon sequestration projects the potential income from the sale of carbon offsets ranges from $823 million to $2.3 billion depending on the discount rate through 2050 and ranges from $985 million to $3.3 billion depending on the discount rate for 100% of the land through 2109. Potential income is detailed below in Table 3.

Table 3: Potential Income from the Sale of CO_2 Offset Allowances Using Multiple Discount Rates When a National CO_2 Program is in Place

	Hectares of Land	Net Present Value of Potential Income from Carbon Sequestration					
		3% Discount Rate		5% Discount Rate		7% Discount Rate	
		2010 To 2050	2010 To 2108 (100 Years)	2010 To 2050	2010 To 2108 (100 Years)	2010 To 2050	2010 To 2108 (100 Years)
Potential Income Per Hectare	1	$3,327	$5,131	$2,001	$2,651	$1,256	$1,503
With 1% of Land	6,556	$21,814,500	$33,637,125	$13,121,952	$17,378,647	$8,236,811	$9,852,740
With 5% of Land	32,781	$109,072,501	$168,185,624	$65,609,761	$86,893,236	$41,184,053	$49,263,699
With 10% of Land	65,563	$218,145,002	$336,371,248	$131,219,523	$173,786,472	$82,368,106	$98,527,398
With 50% of Land	327,815	$1,090,725,012	$1,681,856,239	$656,097,613	$868,932,361	$411,840,530	$492,636,990
With 100% of Land	655,630	$2,181,450,025	$3,363,712,477	$1,312,195,226	$1,737,864,721	$823,681,060	$985,273,980

Also, to demonstrate the uncertainty surrounding climate change legislation, potential income from the sale of CO_2 offset allowances in the absence of a national cap and trade program. Table 4 below shows potential income from the sale of offset allowances in six different sensitivity analysis scenarios when only the RGGI program is in place throughout the entire time period. All values are the net present value of the sale of the offsets in two time scenarios, 2010 through 2050 and 2010 through 2109 (a 100 year timeframe).[9] The net present value ranges from $114 to $237 depending on the discount rate for a single hectare of land through 2050 and ranges from $121 to $281 depending on the discount rate for a single hectare of land through 2109. If all available forest land is able to be utilized for carbon sequestration projects the potential income from the sale of carbon offsets ranges from $74 million to $155 million depending on the

[8] Net present value is the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects using a specific discount rate. A discount rate of 7% was used for this analysis.
[9] Net present value is the total present value (PV) of a time series of cash flows. It is a standard method for using the time value of money to appraise long-term projects using a specific discount rate. A discount rate of 7% was used for this analysis.

discount rate through 2050 and ranges from $79 million to $184 million depending on the discount rate for 100% of the land through 2109. Potential income is detailed below in Table 4.

Table 4: Potential Income from the Sale of CO_2 Offset Allowances Using Multiple Discount Rates Without a National CO_2 Program is in Place

	Hectares of Land	Net Present Value of Potential Income from Carbon Sequestration					
		3% Discount Rate		5% Discount Rate		7% Discount Rate	
		2010 To 2050	2010 To 2108 (100 Years)	2010 To 2050	2010 To 2108 (100 Years)	2010 To 2050	2010 To 2108 (100 Years)
Potential Income Per Hectare	1	$237	$281	$161	$177	$114	$121
With 1% of Land	6,556	$1,552,800	$1,845,027	$1,056,033	$1,162,726	$749,717	$790,640
With 5% of Land	32,781	$7,764,001	$9,225,133	$5,280,167	$5,813,632	$3,748,587	$3,953,199
With 10% of Land	65,563	$15,528,001	$18,450,266	$10,560,334	$11,627,264	$7,497,173	$7,906,398
With 50% of Land	327,815	$77,640,007	$92,251,331	$52,801,672	$58,136,318	$37,485,866	$39,531,988
With 100% of Land	655,630	$155,280,013	$184,502,663	$105,603,345	$116,272,636	$74,971,732	$79,063,977

Potential Income from the Sale of Class I Renewable Energy Certificates

In 2006 the state of New Jersey passed legislation that required 22.5% of the state's electricity to come from renewable sources by the year 2020. Of the 22.5%, 17.88% of the requirement must come from Class I renewable energy. Class I renewables include wind, solar-electric generation, fuel cells powered by renewable fuels, geothermal technologies, wave and tidal action, methane gas from landfills, anaerobic digestion of food waste or sewage sludge at a biomass facility, and other biomass resources provided that the biomass is cultivated and harvested in a sustainable manner.[10] In order to comply with the regulation, electric power suppliers must purchase or produce Renewable Energy Certificates (RECs), which represent the environmental attributes of one megawatt-hour (MWh) of generation from an eligible facility. RECs are bought and sold by suppliers in order to meet the requirements. The market has been in place since 2006, and the analysis provided assumes that the market will stay in place until the year 2020. Forecasted trading prices were derived from modeling work performed for the New Jersey Energy Master Plan.[11] The 2010 through 2020 forecast for Class I RECs is below in Table 5.

[10] DSIRE, *New Jersey Renewable Portfolio Standard*. Available at http://www.dsireusa.org/incentives/incentive.cfm?Incentive_Code=NJ05R&re=1&ee=1.

[11] Center for Energy, Economic & Environmental Policy, *Modeling Report for the New Jersey Energy Master Plan*, October 2008. Available at http://www.state.nj.us/emp/docs/pdf/10122208ceeepModEMP.pdf.

Table 5: Class I REC Price Forecast

	REC Forecast ($/MWh)
2010	15.59
2011	16.97
2012	18.35
2013	19.72
2014	21.10
2015	22.48
2016	20.62
2017	18.76
2018	16.89
2019	15.03
2020	13.17

It is estimated by the Rutgers EcoComplex that there is almost 1,700 megawatts (MW) of potential Class I biomass facilities. This information is drawn from Section 3 of this report and is discussed in more detail in that section. It is important to note that the 'technical potential' is theoretically the maximum amount of biomass capacity that is possible throughout New Jersey. The realized amount of biomass capacity is expected to be significantly less than the technical potential. Of this biomass potential, it is unknown the specific amount of generating facilities that will qualify for Class I RECs. The table below shows the potential revenue the sale of Class I RECs under five different scenarios. The five scenarios are if 1% of the potential capacity is realized, if 5% of potential capacity is realized, if 10% of the potential capacity is realized, if 50% of the potential capacity is realized, and if 100% of the potential capacity is realized and qualifies. All values are the net present value of the sale of the RECs. The net present value ranges from $18 million to $21.5 million depending on the discount rate if 1% of the biomass potential is realized and qualifies to $1.8 billion to $2.1 billion depending on the discount rate if 100% of the biomass potential is realized and qualifies. The average revenue per year ranges from $1.8 million to $2.1 million depending on the discount rate if 1% of the biomass potential is realized and qualifies to $182 million to $215 million depending on the discount rate if 100% of the biomass potential is realized and qualifies Potential income is detailed below in Table 6.

Table 6: Potential Income from the Sale of Class I RECs Using Multiple Discount Rates

	MW Capacity	Net Present Value of Potential Income from REC Sales					
		3% Discount Rate		5% Discount Rate		7% Discount Rate	
		2010-2020	Avg. Revenue Per Year	2010-2020	Avg. Revenue Per Year	2010-2020	Avg. Revenue Per Year
Potential Income with 1% of Capacity	17	$21,591,642	$2,159,164	$19,792,271	$1,979,227	$18,228,974	$1,822,897
With 5% of Capacity	84	$107,958,211	$10,795,821	$98,961,353	$9,896,135	$91,144,869	$9,114,487
With 10% of Capacity	168	$215,916,422	$21,591,642	$197,922,706	$19,792,271	$182,289,739	$18,228,974
With 50% of Capacity	839	$1,079,582,111	$107,958,211	$989,613,528	$98,961,353	$911,448,694	$91,144,869
With 100% of Capacity	1,679	$2,159,164,221	$215,916,422	$1,979,227,057	$197,922,706	$1,822,897,388	$182,289,739

Summary and Conclusions

The market for carbon offsets, especially at a national level, is extremely uncertain and the carbon sequestration projects that will qualify as offsets are unknown. The regional market is already in place and trading has occurred for a few years, but the national market is still in the infant stages of discussion. The markets that are in place and the projects that qualify determine the amount of potential income from the sale of CO_2 allowances. If a national market is in place and multiple facilities qualifying for offsets the potential income could be significant. If 5% of New Jersey's rural forest land (32,781 hectares) qualifies for sequestration projects the potential income ranges from $41 million to $109 million through 2050 depending on the discount rate. If only a regional market is in place the potential income is significantly less. If 5% of New Jersey's rural forest land qualifies for sequestration projects the potential income ranges from $3.7 million to $7.7 million through 2050 depending on the discount rate. The revenue stream for Class I RECs is more certain, but the potential capacity installed is very uncertain. If 5% of the potential capacity can be built (84 MW) the income generated from the sale of Class I RECs ranges from $91 million to $108 million through 2020 depending on the discount rate.

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