GUIDELINES TO MEASURE CARBON SEQUESTRATION IN ALABAMA FORESTS

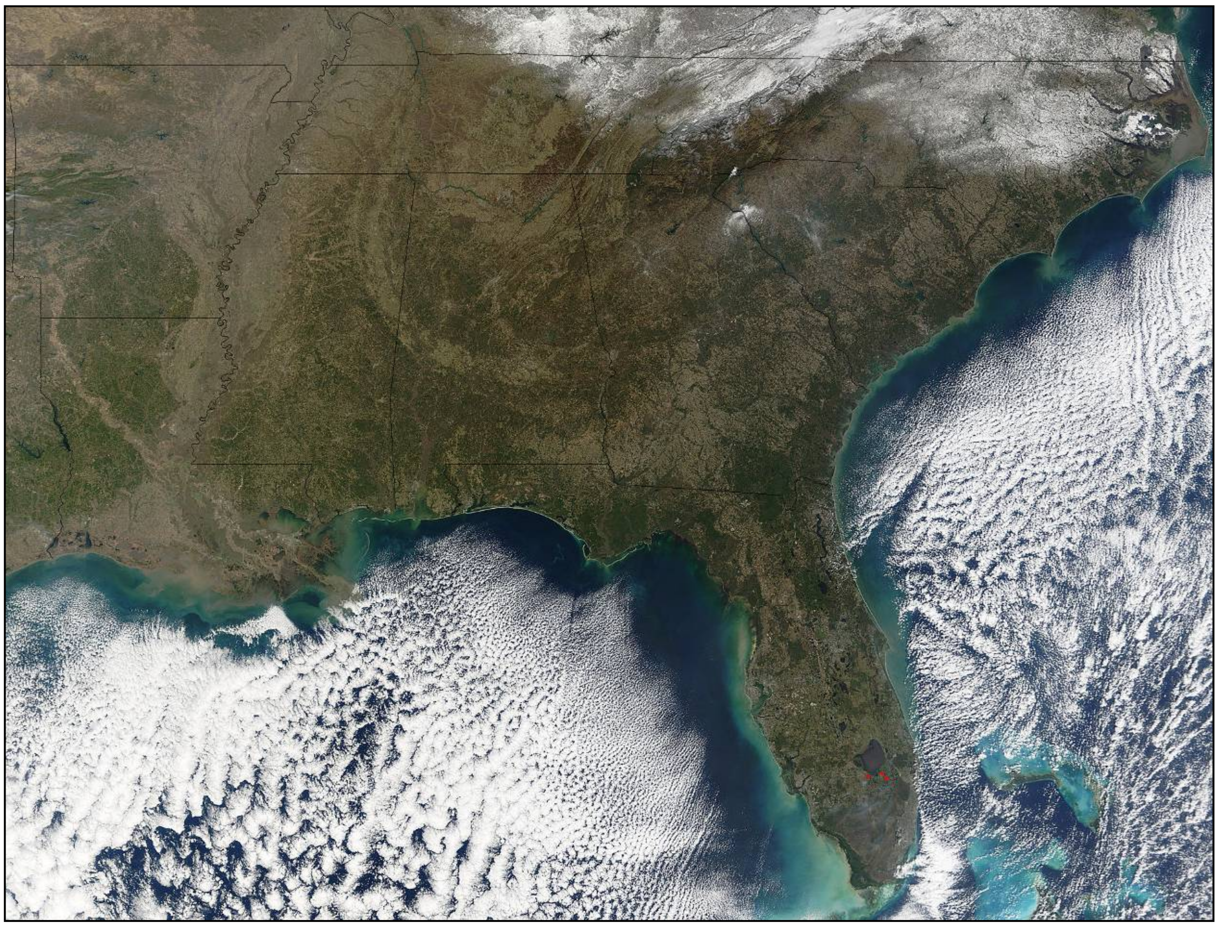

Photo Credit: Jeff Schmaltz, NASA

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FOREWORD

Forests are being recognized in financial markets for the ecosystem services that they provide, such as biomass for renewable energy, clean water, clean air, habitat for wildlife (especially threatened & endangered species) and now carbon sequestration. Carbon storage is one method used to offset carbon emissions in the form of Carbon Dioxide (CO_2), which increases global warming.

We are living in a very exciting time. As the world adapts in order to be more efficient in using the Earth's natural resources, it is encouraging to know that forest landowners, everyday citizens who care about and want to be in tune with nature, will be making such a tremendous impact. The advantage of forests providing these new ecosystem services versus other systems, such as algae farms for energy, or underground storage tanks for carbon dioxide, is that our forests naturally provide so many additional benefits while storing carbon. Additionally, these new markets will not only reduce our energy needs from foreign countries and reduce global warming but will also grow the economy, and more specifically reward forest landowners with increased revenue opportunities for their forestland.

I am pleased to distribute this publication presenting the methodology to measure carbon (and indirectly the traded unit, CO_2) that is produced by and stored in trees grown in Alabama. In order to sell carbon on the emerging trading platforms, a forest landowner (or their forestry consultant) must know how much carbon they have to offer. This publication takes the user through a step-by-step process to determine the carbon that your forests produce in an easy-to-follow process with examples.

In order to further simplify the process, an accompanying Microsoft© Excel Spreadsheet allows the user to enter information specific to their forestland and determine the amount of carbon credits produced without needing to work through a multitude of complicated formulas. We hope forest landowners and professional foresters will find this publication helpful, and with these tools you will be able to participate in the emerging carbon trading markets.

The Alabama Forestry Commission maintains this and more detailed information on our website, ***www.forestry.alabama.gov***, under the ***"Market & Information Resources -- Carbon Sequestration"*** section. I urge you to either visit our web site or contact our economic development section by calling 334-240-9300 for further information or detailed analysis for your particular needs and area.

Sincerely,

Linda Casey

Linda S. Casey,
Alabama State Forester

Alabama Forestry Commission's
Guidelines to Measure Carbon Sequestration in Alabama Forests[1]

(Draft 2 Unpublised, Revised 12/09/2009)

INTRODUCTION

International agreements recognize forestry activities as one way to sequester carbon, which reduces the carbon dioxide (CO_2) levels in the atmosphere and minimizes predicted global temperature increases. In addition, forests provide other amenities that alternative carbon storage systems do not provide, such as clean air and water, wildlife habitat (especially for threatened and endangered species), protection from soil erosion, wood products, and recreation for humans. The following guidelines take a user through a step-by-step process to measure carbon accumulations in Alabama's forests. With this information forest landowners can then sell their carbon credits on emerging trading platforms.

The U.S. emits about 6.3 billion tons of CO_2.

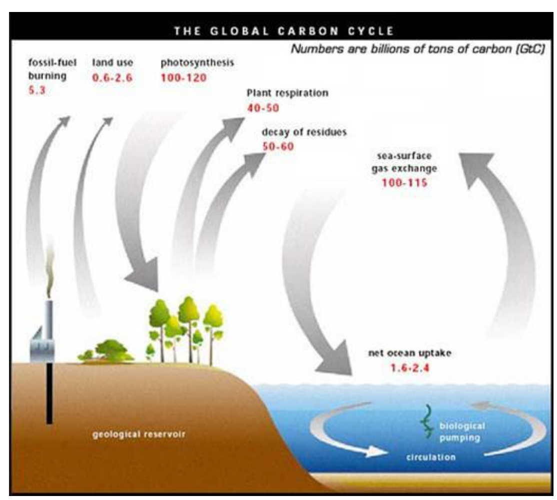
U.S. forests sequester about 10% of the country's CO_2 fossil fuel emissions.

An average acre of managed southern pine stand can annually sequester 3 - 16 tons of CO_2.

Source: USDA FS, EPA

Section 1605(b) of the Energy Policy Act of 1992 directed DOE to issue guidelines establishing a voluntary greenhouse gas reporting program. DOE incorporated USDA Forest Service guidelines in their Section 1605(b) Technical Guidelines and Forestry Appendix.[2] **The guidelines presented in this publication are based primarily on DOE's guidelines.**

These guidelines only provide methodology to measure carbon (and CO_2 equivalent) storage in trees. These guidelines do not include considerations for trading CO_2 credits, such as appropriate trading platforms, trading contracts, aggregation processes, and third-party verification system. Most trading platforms in the United States, such as the Chicago Climate Exchange® (CCX), use DOE's Section 1605(b) guidelines as a template to their specific reporting requirements, but landowners should be aware that there are differences.



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An accompanying Microsoft© Excel Spreadsheet allows the user to enter information specific to their forestland and determine the amount of carbon credits produced without needing to work through a multitude of complicated formulas. This publication and accompanying spreadsheet may be downloaded from the Alabama Forestry Commission's website, ***www.forestry.alabama.gov***, under the ***"Market & Information Resources -- Carbon Sequestration"*** Section.

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[1] *This publication was developed by Bruce Springer, Registered Forester #1264, Alabama Forestry Commission.*

[2] *To develop the measuring and reporting guidelines for forestry activities, DOE worked closely with the USDA Forest Service. These documents are referenced on the AFC website or from DOE's website, http://www.eia.doe.gov/oiaf/1605/gdlins.html.*

FOREST PROJECT TYPES

Separating forest stands in distinct **"Forest Project Types"** is necessary in order to apply the correct estimation methodology. This publication will focus on three distinct forest project types:

UNIQUE OR NON-HOMOGENEOUS FORESTS: Direct measurements are used in estimating carbon in ongoing forest management of **unique or non-homogeneous forests** that are actively managed under a variety of regimes, especially where forest conditions and management practices do not match regional trends. These may include all-aged, natural, or mature timber and can be highly variable. Projections are made either using past growth measurements or regional growth and yield models for similar forest types.	
HOMOGENEOUS FORESTS: Carbon is typically estimated using growth and yield tables (projections) in **plantations and large landholdings of similar forest conditions** where direct measurement would be cost prohibitive. These projects must have forest conditions that are typical of the region. (Typically, limited forest management activities are allowed because it is difficult to account for various management regimes in growth and yield tables and growth models.)	
HARVESTED WOOD PRODUCTS: Carbon continues to be stored in **harvested wood products,** such as finished lumber, plywood, and furniture products. Carbon in some harvested wood products, such as paper, remains only for a short time (1 to 5 years), while carbon in solid wood products, such as lumber and plywood, is stored for long periods (up to 100 years) before returning to the atmosphere.	

CARBON POOLS

Carbon Pools refer to the different components of a forest that stores carbon. Carbon is sequestered in living growing trees, principally as wood in the **tree's main stem**, **branches, foliage**, and **roots**. These are considered **live tree carbon pools**. Carbon is also stored in **dead standing or fallen wood**, forest floor **litter**, and the **organic soil**. Carbon increases in soil are minor in typical southern forests and will not be measured.

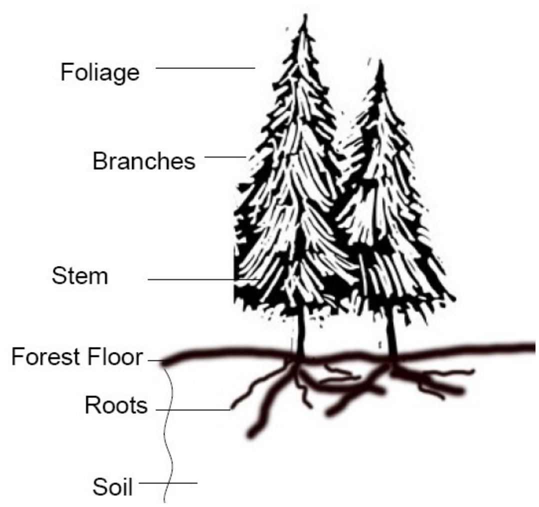
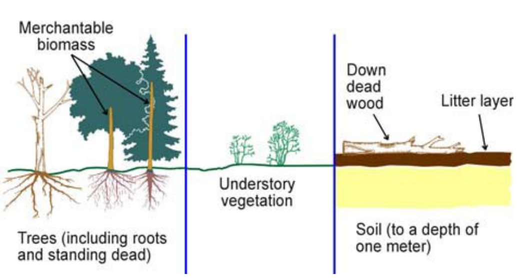


Photo: Richter et al, 1995



DEFINITION OF CARBON AND CARBON DIOXIDE (CO_2) UNITS

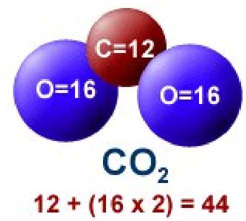
All final measures of net emissions and net emission reductions should be expressed in the form of carbon dioxide equivalent in metric tonnes **($MTCO_2e$)**, which is typically the unit traded in the marketplace. An equivalent metric tonne of CO_2 is abbreviated **$MTCO_2e$**.

1 English or short ton = 2,000 pounds

1 Metric Tonne (MT) = 2,204 pounds

1 English or short ton = 0.9072 metric tonnes (MT)

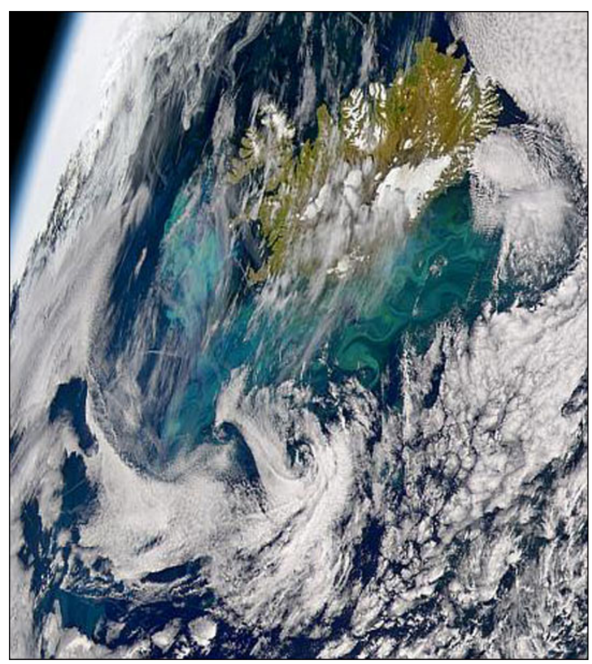
A molecule of carbon dioxide includes the weight of the gas, which is more than the weight of the carbon alone because the gas also includes two oxygen atoms. A simple multiplication factor, **3.67**, can be used to convert carbon to carbon dioxide equivalent.[3]



1 unit of Carbon = 3.67 units CO_2

ACCURACY OF CARBON DIOXIDE (CO_2) MEASUREMENTS

As previously mentioned, the most accurate way to estimate stored carbon and subsequently CO_2 equivalents is to **directly measure** the trees on a specific site (project). This involves developing and implementing a sampling inventory or timber cruise. This method is the most costly but also the most accurate. In most situations, forest landowners should utilize a Registered Forester to conduct these measurements.[4] Most often, only living and merchantable trees are measured since they store the majority of carbon sequestered.



Another approach to estimate stored carbon is to use **regional look-up tables** that represent average forest conditions for a region, stand age, forest condition, and productivity class. The average values presented in the look-up tables can then be applied to similar conditions on a specific site. Although this approach is inexpensive, it is not as accurate as directly measuring biomass. Because of this uncertainty, carbon purchasers may not pay for the entire carbon stored until late in the contract period, or they may require a discount.

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[3] *The multiplication factor of 3.67 is derived by comparing the molecular weight of carbon of 12 with the molecular weight of oxygen of 16. CO_2 = 12+16+16=44. C = 12. As carbon combines with oxygen the total molecular weight increases at a consistent ratio of 44/12, which rounds to 3.67. Image courtesy of U.S. Department of Energy.*

[4] *For a listing of Registered Foresters providing services in your area, visit the Alabama Forestry Commission's website.*

A third approach to estimate stored carbon is to use **regional growth & yield models** for similar forest conditions and activities representative of a specific site. In some cases, these models may be more accurate than look-up tables but may require more time and expense. If a modeling approach is used, periodic validation of model estimates is strongly recommended. Models may also be used to update inventories of carbon stocks for annual reporting in the years in between direct measurements. A user-friendly model developed by the USDA Forest Service called **Carbon Online Estimation** (COLE) is available via a web interface at **http://ncasi.uml.edu/COLE/.** COLE provides customized estimates of forest carbon pools for different regions in the United States and is based on FIA and 1605(b) information.

The procedures in DOE's Section 1605(b) further define a rating system for the various carbon measuring methods, with a rating of "A" being the most accurate and a rating of "D" being the least accurate, as shown in the following table. Obviously both the buyer and seller in a carbon trading agreement would prefer trading carbon where the amount estimated is the most reliable, i.e. measured in such a way that they are considered class "A" carbon units. For example, landowners that have class "A" carbon estimates have a more reliable estimate than other landowners that have class "C" estimates.

RATING	CHARACTERIZATION	APPLICATION OF LOOK-UP TABLES
A	**Most accurate** (within 10 % of true value at a 95% Confidence Level)	Uses **direct measurements** or estimates in look-up tables validated with direct measurements for the specific site and management conditions.
B	**Adequate accuracy** (within 20 % of true value)	Estimates in **regional look-up tables** modified or adjusted to match the specific site and management conditions. **Growth & Yield Models** closely mimic actual forest conditions. (Regional look-up tables and/or regional growth & yield models are usually used for premerchantable trees and plantations.)
C	**Marginal accuracy** (within 30 % of true value)	Typical application of **regional look-up tables** that generally match the site and management conditions. Sites are defined by region, forest type, productivity class, and management schemes. **Regional growth & yield models** that allow little site specific input and variances in management schemes.
D	**Inadequate accuracy**	Use of look-up tables for specific sites or management conditions that are not represented by the tables. For example, using the South Central, average loblolly pine table for an intensively managed, thinned plantation.

DIRECT MEASUREMENT OF CO_2 STORAGE OF TREES (Rating A)

The most accurate way to estimate carbon dioxide storage of trees is to directly measure trees using standard forest inventory procedures and then calculate the carbon dioxide storage potential based on these tree measurements. Direct measurement is the most accurate (will usually be classified as "A" units) but is also the most costly estimation process. Direct measurements will be necessary in **unique or non-homogeneous forests projects.**

Most forest inventories measure live trees as cords, board feet, or tons. Because carbon dioxide is traded in tons, and biomass tons can be obtained from a tree inventory, tons will be used as the base unit in calculating carbon accumulations (and subsequently CO_2 equivalents).

USE THE FOLLOWING SIX STEP PROCESS TO DETERMINE ENTIRE LIVE TREE, ABOVE-GROUND CARBON DIOXIDE (CO_2) EQUIVALENT:[5]

STEP 1: INVENTORY MERCHANTABLE ROUNDWOOD. Using traditional forest inventory procedures estimate the green tons of merchantable roundwood biomass (i.e. pulpwood, sawtimber, etc.) in the main tree's bole or stem. If the inventory includes bark, multiply green tons of wood and bark by 0.9 to obtain an estimate of green tons of wood only for each product.

The accompanying spreadsheet includes stock tables (in short tons) for the main forest products harvested in Alabama. (These tables are provided for your convenience and it is not required that you use them.)

If inventory volumes are reported in units other than tons, to convert to tons use either local conversion factors or the following general conversion factors:

Pine Sawtimber and CNS:	**7.50 tons per MBF, Scribner**
Pine Pulpwood:	**2.68 tons per cord**
Hardwood Sawtimber:	**8.75 tons per MBF, Doyle**
Hardwood Pulpwood:	**2.90 tons per cord**
From cubic feet to cords:	**90 cubic feet (ft^3) per cord (solid wood & bark)**

STEP 2: ESTIMATE TOTAL TREE BIOMASS. There is considerably less biomass in the merchantable roundwood (i.e. pulpwood, sawtimber, etc.) than in the entire tree. However, carbon is stored in the entire tree including the limbs and tree tops and should be included. To estimate entire tree biomass from merchantable roundwood biomass, multiply the inventory weights calculated in STEP 1 by the following conversion factor for the general species group listed below. This will provide an estimate of the green weight of the entire tree.

Merchantable to Total Tree Conversion Factors:

Softwood	Hardwood	Average
1.12	1.33	1.19

[5] *The conversion rates/multipliers used in the following steps are identified in the Department of Energy's (DOE) Energy Policy Act, Section 1605(B), Voluntary Reporting Guidelines of Greenhouse Gases, Forestry Appendix, except as otherwise identified.*

STEP 3: CONVERT FROM GREEN TONS TO DRY TONS. Multiply green tons of the entire tree obtained in STEP 2 by the specific gravity[6] conversion factor for the general species groups listed below. This will provide an estimate of the dry weight of the entire tree.

Specific Gravity Conversion Factors:

Softwood	Hardwood	Average
0.463	0.529	0.500

STEP 4: CONVERT TREE BIOMASS TO CARBON EQUIVALENT. Multiply the dry tons of the entire tree obtained in STEP 3 by **0.5** to obtain a comparable weight of entire tree's sequestered carbon.

STEP 5: CONVERT CARBON TO CARBON DIOXIDE EQUIVALENT. Multiple the tons of sequestered carbon obtained in STEP 4 by **3.67** to obtain a comparable weight of carbon dioxide equivalent (CO_2).

STEP 6: CONVERT SHORT TONS TO METRIC TONNES. Typical southern forest inventories are reported in English or short tons, which equals 2,000 pounds. Most Carbon Dioxide is traded based on metric tonnes, which equals 2,204 pounds. To convert to metric tonnes multiply the short tons by **0.9072**.

A **generalized formula** to estimate metric tonnes carbon dioxide equivalent ($MTCO_2e$) using traditional timber inventory roundwood estimates (reported in short tons) is as follows:

$MTCO_2e$ = (Merchantable Weight) x (Total Tree Factor) x (Specific Gravity Factor) x 0.50 x 3.67 x 0.9072

EXAMPLE: DIRECT MEASUREMENT OF CO2 STORAGE OF TREES
A landowner hired a registered forester to estimate the merchantable volume of a natural stand of mixed pine-hardwood covering 85 acres in northeast Alabama. The registered forester estimated a total of 765 cords of pine pulpwood, 272 MBF (Scribner) of pine sawtimber, 425 cords of hardwood pulpwood, and 119 MBF of hardwood sawtimber (Doyle).

Step 1: Convert merchantable estimates to short ton equivalents by general species group:
PPW (765 x 2.68) + PST (272 x 7.50) = 4,090 short tons of softwood on 85 acres
HPW (425 x 2.90) + HST (119 x 8.75) = 2,274 short tons of hardwood on 85 acres

Step 2: Estimate total tree biomass (green tons):
4,090 x 1.12 = 4,581 short tons tree biomass, softwood
2,274 x 1.33 = 3,024 short tons tree biomass, hardwood

Step 3: Convert to dry tons using specific gravity ratios:
4,581 x 0.463 = 2,121 short tons tree biomass, softwood, DRY
3,024 x 0.529 = 1,600 short tons tree biomass, hardwood, DRY

Step 4: Convert to carbon tons equivalent:
(2,121 + 1,600) x 0.5 = 1,861 short tons carbon equivalent

Step 5: Convert to CO_2 tons equivalent:
1,861 x 3.67 = 6,830 short tons carbon dioxide (CO_2) equivalent

Step 6: Convert to CO_2 metric tonnes equivalent:
6,830 x 0.9072 = **6,196** metric tonnes carbon dioxide equivalent ($MTCO_2e$)

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[6] *Average wood specific gravity is the density of wood divided by the density of water based on wood dry mass associated with green tree volume.*

DIRECT MEASUREMENT OF CO_2 ANNUAL CHANGES IN TREES USING INCREMENT CORES SAMPLES (Rating A)

The six step process above estimates current CO_2 amounts on a specific site and is commonly referred to as a **baseline inventory**. Changes in CO_2 can either be positive (carbon sequestration) or negative (carbon emissions). CO_2 **changes** are the marketable commodity which is traded. CO_2 changes can be estimated by using recent tree growth trends to project future annual biomass increases. Many forest inventory computer programs also provide growth projections.

The Alabama Forestry Commission recommends that while a baseline inventory is conducted the forester take increment core samples to measure the past diameter growth of a representative sample of trees, and then use the past growth measurements to project future annual growth between the baseline and subsequent inventories. In the procedures that follow, tree diameter growth and related entire tree biomass Periodic Growth (recorded as a percentage change) can be calculated using the following formula:

$$\textbf{Periodic Growth (\%)} = 1 - (\text{Sum } (dib_s/DIB_s)^2 \;/\; \text{Number Sample Trees})$$

Where: dib_s = Diameter Inside Bark (DIB) **periods** ago of sample tree
DIB_s = Diameter Inside Bark (DIB) **present** of sample tree
periods = Usually 5 or 10 years ago in CO_2 markets

To estimate annual growth, divide periodic growth by number of periods, as shown in the formula below. (This assumes a direct linear increase in growth during the period measured.)

Annual Growth (%) = Periodic Growth / Number of Periods

To calculate annual growth, simply enter information from growth sample measurements taken during the timber inventory cruise into the accompanying spreadsheet. For every growth sample tree enter current DBH, radial bark thickness, and the periodic radial growth. Calculations are built in.

See the example on the next page . . .

EXAMPLE: BIOMASS GROWTH ESTIMATE BASED ON INCREMENT CORE SAMPLE

In this example, while performing the baseline inventory, five increment core growth sample trees were also measured, and tree diameter at 4½ feet (DBH), radial bark thickness, and past 10-year radial growth was recorded.

Calculation of Tree Growth:

Property:	Stand:	Period (usually 10):
Example	1	10

For each cell below, enter the Current DBH, Radial Bark Thickness and Past Radial Growth for time period (usually 10 years) for each sample growth tree measured:
(maximum 50 growth trees)

Current DBHs	Radial Bark Thicknesss	Period Radial Growth	Current DBHs	Radial Bark Thicknesss	Period Radial Growth
8.4	0.4	2.9			
6.7	0.35	2			
10.2	0.45	3.9			
12	0.4	4.8			
9.6	0.4	3.4			

NUMBER OF GROWTH TREES =	5
PERIOD GROWTH (%) =	38.8%
ANNUAL GROWTH (%) =	3.88%

The calculated annual growth percentage may then be applied to the baseline CO_2 equivalents to obtain annual projected CO_2 changes between inventory years.

Continuing with the example, the sample trees indicate an annual growth increase of 3.88 percent. Applying this to the estimated 6,196 $MTCO_2e$ stored in the 85 acres of pine-hardwood, would estimate an annual increase of 240 $MTCO_2e$ per year (6,196 x 0.0388) for the current growing year, based on the last 10 year's of growth.

The estimated amount stored at the end of the next growing cycle would be 6,436 $MTCO_2e$ (6,196 metric tonnes x 1.0388). The CO_2 amount accumulated and stored during the next five years is estimated as follows:

Projection Year	Beginning Inventory	Annual Growth	Ending Inventory
1	6,196 $MTCO_2e$		6,436 $MTCO_2e$
2	6,436 $MTCO_2e$		6,686 $MTCO_2e$
3	6,686 $MTCO_2e$	**x 1.0388 =**	6,946 $MTCO_2e$
4	6,946 $MTCO_2e$		7,215 $MTCO_2e$
5	7,215 $MTCO_2e$		7,495 $MTCO_2e$

ACCURACY OF DIRECT ESTIMATES

It is important to know how accurate an estimate of carbon storage is for a particular ownership. DOE's Section 1605(b) guidelines rate carbon estimates based on levels of measurement precision, with an "A" rating given to precisions levels where the estimate is within 10% of true value at a 95% confidence interval, as shown in a previous section. A ton of carbon estimated with an "A" rating should be more valuable than another ton with a "C" rating.

It is possible to measure the accuracy of the inventory during an inventory (cruise) if the forester keeps tree tallies separated by sample plot. The accuracy level will also assist in deciding whether or not enough sample plots were measured to be within a specific accuracy level. Again, the accompanying spreadsheet has built in calculators to determine the accuracy level.

THE FOLLOWING STEPS SHOULD BE USED TO MEASURE THE ACCURACY OF AN INVENTORY:

STEP 1: RECORD TREES TALLIES BY SAMPLE PLOT. During the forest inventory, record the trees while standing at plot center and keep each plot separate from the others. Many forest inventory programs are designed to do this. If the timber tract is stratified, then also keep inventory data separated by strata.

STEP 2: CALCULATE PER ACRE MERCHANTABLE TIMBER VOLUME, AND CORRESPONDING $MTCO_2e$ BY SAMPLE PLOT. When the forest inventory is completed, for each sample plot calculate the per acre total merchantable tree volume, weight, and carbon dioxide equivalent using the steps presented in the earlier section of this document.

STEP 3: CALCULATE THE $MTCO_2e$ MEAN, STANDARD DEVIATION, STANDARD ERROR, AND NUMBER OF PLOTS NEEDED TO OBTAIN THE DESIRED ACCURACY LEVEL USING STANDARD STATISTIC FORMULAS. To do this simply enter the carbon dioxide equivalents per acre for each sample plot into the accompanying spreadsheet. Calculations are built in.

EXAMPLE: ESTIMATING ACCURACY OF DIRECT MEASUREMENTS
Continuing from the previous example, the forester estimated the timber volume in the pine-hardwood stand initially using 16 sample plots. The table below shows the volume estimates derived from each plot. These estimates were then converted to equivalent CO_2 estimates.

Plot#	Per Acre Weight Estimate	Multiplier to Convert to $MTCO_2e$	Per Acre ($MTCO_2e$)
1	77	Using the "**All**" category and not separating softwood from hardwood, the multipliers are: **Merchantable Weight x 1.19 x 0.50 x 0.50 x 3.67 x 0.9072** which can be simplified to: **Merchantable Weight x 0.99**	76
2	78		77
3	74		73
4	92		91
5	95		94
6	96		95
7	62		61
8	61		60
9	63		62
10	73		72
11	78		71
12	73		72
13	61		60
14	68		67
15	79		78
16	74		73
AVERAGE	**74.9**		**73.9**

The following table shows the results of entering the CO_2 equivalents per acre into the accompanying spreadsheet. The mean, standard deviation, standard error, confidence interval, and number of plots needed to obtain a true value within 10% (at a 95% confidence level) are automatically calculated as sample point estimates are entered into the yellow-shaded fields. Up to 100 points can be entered.

Calculation of Sampling Precision:

Property: Example | Stand: 1

For each cell below, enter the volume or weight estimate determined at each sample point for which you wish to calculate the appropriate statistics: (maximum 100 sample points)

76.0	77.0	73.0	91.0	94.0
95.0	61.0	60.0	62.0	72.0
71.0	72.0	60.0	67.0	78.0
73.0				

CONFIDENCE LEVEL (Default = 95%) **95%**

t-distribution value for selected Confidence Level & Number of Sample Points: 2.120

PRECISION LEVEL (within % +/- mean, Default = 10%) **10%**

NUMBER OF SAMPLE POINTS TAKEN: **16**

MEAN VALUE OF SAMPLE POINTS: **73.9**

STANDARD DEVIATION: **10.4**

STANDARD ERROR: **2.6**

CONFIDENCE INTERVAL: **73.9 +/- 5.1**

SAMPLE PLOTS NEEDED: **9**

You have taken enough sample points.

The 16 samples provide an estimate of 73.9 $MTCO_2e$ with a confidence interval of +/- 5.1 tonnes at a 95% confidence level. Based on the variability of the measurements, it was only necessary to take 9 plots to have a confidence level within 10% of the mean with a 95% confidence level. Did the 16 plots provide an accurate estimate to meet DOE's qualifications for this CO_2 estimate to be classified as an "A"? The answer is "YES".

INDIRECT ESTIMATE OF CO_2 STORAGE OF TREES USING GROWTH AND YIELD TABLES (Rating B, C, & D)

Carbon is typically estimated using growth and yield tables (projections) in **plantations and large landholdings of similar forest conditions** where direct measurement would be cost prohibitive. These **homogeneous forests projects** must have forest conditions that are typical of the region. DOE Section 1605(b) procedures include a variety of look-up tables based on actual forest conditions. The accuracy of these tables depends on how closely your specific forest condition matches the regional tables and whether or not actual measurements are used to verify estimates. Using growth and yield tables can provide estimates with ratings of either B, C, or D.

AFFORESTATION includes the establishment of forest or forest stands on lands that have not been recently forested (during the last ten years). Afforestation Projects typically occur on cultivated or pastured farmland with associated increase site potential which is reflected in higher carbon storage rates than reforestation projects.

REFORESTATION is similar, but refers to the re-establishment of forest cover, naturally or artificially, on lands that have recently been harvested or otherwise cleared of trees.

Alabama is considered part of the **South-Central Region** with respect to these look-up tables, which are shown on the following page. There are six general forest conditions listed for the South-Central Region. These tables show estimated merchantable tree biomass volume (under the heading **"Mer. Wt.")** and total CO_2 estimates (under the heading **"Total MTCO$_2$e")** by stand age and general forest condition. The CO_2 estimate under the **"Total MTCO$_2$e"** column includes live standing trees, standing dead trees, understory vegetation, down deadwood, and forest floor CO_2 accumulations. It does not include carbon stored in the soil or carbon in live tree roots. These are per acre rates.

THE FOLLOWING STEPS SHOULD BE USED TO DETERMINE CO_2 ESTIMATES FOR YOUR SPECIFIC FOREST STAND:

STEP 1: SELECT APPROPRIATE TABLE. Decide which table (Afforestation or Reforestation) to use based on your forest's origination.

STEP 2: DETERMINE CURRENT CO_2 LEVEL. Using the appropriate table determine the per acre **Total MTCO$_2$e** entry for your forest's age and condition. This is the estimated CO_2 for your forest in metric tonnes per acre. Sometimes it will be necessary to interpret between the five-year intervals presented in the tables.

STEP 3: DETERMINE ANNUAL CO_2 CHANGE. To estimate the future increase in CO_2, calculate the difference in the current and future year's **Total MTCO$_2$e** entry and divide by the number of years – **this is the estimated annual per acre increase in CO_2.**

STEP 4: CALCULATE TOTAL CO_2 STORAGE IN FOREST STAND. Multiply the per acre rate determined in **Step 3** by the number of acres in the specific forest condition to obtain the total CO_2 increase for your forest stand.

EXAMPLE: INDIRECT ESTIMATE OF CO_2 INCREASES IN TREES

To illustrate, a landowner has 25 acres of 12-year-old mixed Loblolly-Shortleaf pine stand on an abandoned agriculture site.

Step 1: Use the Afforestation Table since this is a new forest established on agriculture land.

Step 2: Under the Afforestation Table, a Loblolly-Shortleaf pine stand is estimated to have at age 10 approximately 52.5 $MTCO_2e$; and at age 15, 69.7 $MTCO_2e$ per acre. This equates to an average annual CO_2 increase of 3.44 metric tonnes per acre ((69.7 - 52.5) / 5). At age 12 the stand is estimated to store 59.38 $MTCO_2e$ per acre (52.5 + 3.44 + 3.44), or 1,484.5 tonnes for the 25-acre stand.

Step 3: This equates to an average annual CO_2 increase of 3.44 metric tonnes per acre ((69.7 - 52.5) / 5).

Step 4: For the entire stand, at 3.44 metric tonnes per acre x 25 acres = 86.0 metric tonnes of annual CO_2 increase. This increases when the stand reaches age 16 to 88.0 metric tonnes per year.

The CO_2 amount accumulated and stored during the next five years in the 25-acre pine stand can be projected as follows:

Stand Age	Beginning Inventory	Annual Growth	Ending Inventory
	-------------------	$MTCO_2e$ for 25 acres	-------------------
12	--		1,485
13	1,485	86.0	1,571
14	1,571	86.0	1,657
15	1,657	86.0	1,743
16	1,743	88.0	1,831
17	1,831	88.0	1,919

A good indication of the accuracy of the estimate is how close the actual merchantable volume equals the estimate in the tables (through interpretation of the table, you can estimate that a 12-year-old Loblolly-Shortleaf pine stand typically has approximately 12.6 tons of merchantable volume per acre ((2/5)*(18–9) + 9). If a forest inventory shows different merchantable volumes, adjust the CO_2 table estimates accordingly since actual measurement are more accurate.

For example, if a forest inventory estimated merchantable volume of 16.7 short tons, use interpretation of the tables to calculate the corresponding age and CO_2 estimates as follows:

Age = ((16.7-9)/(18-9))*5 + 10 years ➔ Age = 14.28 years

Estimated $MTCO_2e$ at age 14.28 = (4.28/5)*(69.7-52.5) + 52.5 = 67.22 $MTCO_2e$

CARBON DIOXIDE (CO_2) YIELD TABLES FOR REFORESTATION (Metric Tonnes/Acre)

	Elm-ash-cottonwood		Loblolly-shortleaf pine		Loblolly-shortleaf pine; high productivity and management intensity		Oak-gum-cypress		Oak-hickory		Oak-pine	
Stand age (years)	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$
0	0	31.9	0	38.2	0	54.7	0	27.5	0	32.3	0	40.0
5	0	35.2	0	45.1	0	55.8	0	25.3	0	37.1	0	44.0
10	6	46.6	9	61.7	23	86.6	5	42.2	6	51.0	7	60.9
15	10	59.8	18	76.0	70	137.3	9	59.1	10	63.9	13	76.7
20	16	74.9	29	92.1	117	183.1	16	76.7	16	78.5	21	91.8
25	22	89.2	41	108.3	150	211.8	22	92.1	22	92.5	28	106.4
30	29	103.5	52	120.7	165	224.2	28	105.7	29	106.1	37	119.6
35	36	119.3	63	132.5	167	226.1	35	121.8	36	121.1	46	133.6
40	45	136.2	73	143.1	169	227.2	44	138.4	45	138.4	56	147.5
45	54	153.4	82	153.0	171	228.6	53	153.4	54	153.8	65	160.4
50	63	172.1	91	162.6	172	230.1	61	167.4	63	168.8	73	171.8
55	72	187.2	99	171.0	172	230.5	70	180.9	72	182.8	82	183.1
60	80	201.1	107	178.4	172	230.8	79	195.6	80	196.0	90	194.1
65	88	214.7	114	185.3	172	230.8	89	209.6	88	208.5	97	203.3
70	96	227.2	120	192.3	172	231.2	98	222.8	96	220.2	104	212.1
75	103	238.6	126	197.8	172	231.6	106	234.1	103	230.5	112	221.7
80	109	249.2	132	203.7	172	231.6	113	244.1	109	240.8	118	229.4
85	116	259.5	138	209.2	172	231.9	123	256.5	116	249.9	124	236.3
90	121	268.6	143	214.0	172	232.3	133	269.7	121	258.4	130	243.7

CARBON DIOXIDE (CO_2) YIELD TABLES FOR AFFORESTATION (Metric Tonnes/Acre) (New Establishment on Nonforest Land)

	Elm-ash-cottonwood		Loblolly-shortleaf pine		Loblolly-shortleaf pine; high productivity and management intensity		Oak-gum-cypress		Oak-hickory		Oak-pine	
Stand age (years)	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$	Mer. Wt. (Short Tons/ac)	Total $MTCO_2e$
0	0	6.2	0	6.2	0	6.2	0	2.6	0	6.2	0	6.2
5	0	23.9	0	29.7	0	27.9	0	14.3	0	25.3	0	26.1
10	6	41.1	9	52.5	23	67.9	5	36.7	6	44.8	7	49.2
15	10	56.9	18	69.7	70	124.0	9	56.2	10	60.6	13	68.3
20	16	73.0	29	87.3	117	172.9	16	74.9	16	76.7	21	85.9
25	22	88.1	41	104.6	150	204.4	22	91.0	22	91.4	28	101.7
30	29	103.1	52	118.2	165	218.7	28	105.3	29	105.3	37	116.3
35	36	118.9	63	130.3	167	221.7	35	121.5	36	120.7	46	131.0
40	45	135.8	73	141.7	169	223.9	44	138.0	45	138.0	56	145.7
45	54	153.4	82	151.9	171	226.4	53	153.4	54	153.8	65	158.9
50	63	172.1	91	161.8	172	228.3	61	167.4	63	168.8	73	170.7
55	72	187.2	99	170.3	172	229.0	70	180.9	72	182.8	82	182.0
60	80	201.1	107	178.0	172	229.7	79	195.6	80	196.0	90	193.8
65	88	214.7	114	185.0	172	230.1	89	209.6	88	208.5	97	203.0
70	96	227.2	120	191.9	172	230.5	98	222.8	96	220.2	104	211.8
75	103	238.6	126	197.4	172	231.2	106	234.1	103	230.5	112	221.3
80	109	249.2	132	203.3	172	231.6	113	244.1	109	240.4	118	229.0
85	116	259.5	138	209.2	172	231.6	123	256.5	116	249.9	124	236.0
90	121	268.6	143	214.0	172	231.9	133	269.7	121	258.4	130	243.7

SOURCE: DOE, Energy Policy Act, Section 1605(b), Voluntary Reporting Guidelines of Greenhouse Gases, Forestry Appendix.
Total Nonsoil CO_2 Tonnes/Acre includes live standing tree, standing dead, understory, down deadwood, and forest floor carbon dioxide accumulations.
Carbon Dioxide (CO_2) Equivalents obtained by multiplying carbon estimates by 3.67.
Volume converted from cubic feet (Ft^3) to Short tons (Tons) using a ratio of 1 ton = 30 cubic feet (Ft^3).

NATURAL DISTURBANCES

Carbon in forests may be lost to natural causes such as an insect epidemic, drought, or wildfire. The DOE Guidelines require reporters to make a separate estimate of the effect of natural disturbances. To keep track of changes after disturbance, the entity should identify disturbed land as a separate stratum in the estimation process. It may be necessary to inventory disturbed areas to get a new estimate of the residual carbon storage. Typically, entities cannot report additional reductions associated with increases in carbon storage on lands that have undergone natural disturbances until the carbon stocks return to pre-disturbance levels.

FOREST MANAGEMENT ACTIVITIES

Forestry management activities, such as reforestation or harvesting, can be significant sources or sinks for carbon. Management activities can reduce carbon emissions and increase the levels of carbon stored. Site preparation burning, fertilizing, thinning, salvage cuts, hardwood control, livestock grazing, and many other management activities influence carbon storage in a forest stand. Most of these management activities are excluded from regional carbon estimation tables. However, they are usually included in growth & yield models that allow user inputs for on-site conditions. Periodic inventories also inherently include all management activities in determining current and projected carbon storage. Direct measurement may currently provide the only viable approach to accurately estimate carbon storage where these management activities are ongoing.

SUSTAINABLY MANAGED FORESTS (Source: DOE 1605b?)

Forest certification systems require landowners to harvest at sustainable rates, thus preventing long-term declines in carbon stocks. Carbon stocks in sustainably managed forests will fluctuate in response to natural disturbances, harvest schedules, changes in markets, and changes in technology. Nevertheless, it is valid to conclude that significant long-term declines in forest carbon stocks are unlikely to occur in sustainably managed forests when considering all forests carbon pools such as soil, litter, biomass and long-lived products. Entities may assume there is neither an increase nor decrease in carbon stocks on certified sustainably managed forests.

PROCEDURE TO ESTIMATE BELOW GROUND ROOTS CO_2 SEQUESTRATION

Carbon sequestered by southern forests end up primarily in the live tree, both above and below ground. Below ground carbon includes coarse and fine roots and soil carbon. Research has indicated that soil carbon and fine roots in managed southern forests change very little. They are also difficult to measure. This publication does not present guidelines for estimating soil carbon. If an entitity wishes to measure carbon sequestered in soil carbon pools, the Alabama Forestry Commission directs the reader to two publications by the Forest Service, *"Methods for Calculating Forest Ecosystem and Harvested Carbon with Standard Estimates for Forest Types of the United States (NE-343)"* and *"Measurement Guidelines for the Sequestration of Forest Carbon (NRS-18)."*

Other research studies have indicated that there is a relatively constant relationship between above and below ground living tree biomass. The shoot to root ratio is 4:1, or in other words, 20% of the total tree biomass is below ground.[7] Using this ratio, it is easy to calculate below ground CO_2 sequestration of the live tree's coarse roots.

THE FOLLOWING STEPS SHOULD BE USED TO DETERMINE CO_2 ESTIMATES IN THE ROOTS (taproot and coarse roots) OF LIVING TREE(S):

STEP 1: CALCULATE TOTAL ABOVE GROUND CO_2 IN THE LIVING TREE(S). From the procedures presented in earlier sections of this publication, calculate the total above ground CO_2 equivalent ($MTCO_2e$) of the living tree(s).

STEP 2: ESTIMATE BELOW GROUND ROOTS SEQUESTERED CO_2. Multiply the weight obtained from **Step 1** by **0.25** to estimate the sequestered weight of taproot and other coarse root's CO_2 equivalent ($MTCO_2e$).

EXAMPLE: ESTIMATE BELOW GROUND ROOTS SEQUESTERED CO_2

Step 1: Continuing from the example in the previous section, the total weight estimated for the 85 acres of pine-hardwood forest was **6,196** metric tonnes carbon dioxide equivalent ($MTCO_2e$).

Step 2: Multiply the weight obtained from **Step 1** by **0.25**:

6,196 x **0.25 = 1,549** taproot and coarse root's metric tonnes CO_2 equivalent ($MTCO_2e$).

[7] MacDicken 1997, McKenzie et al. 2000).

HARVESTED WOOD PRODUCTS

Carbon is stored even after trees are harvested and processed into final products. The portion of a forest's carbon that is released to the atmosphere upon harvest depends upon how the timber is used. For example, burning woody biomass for energy releases the stored carbon immediately, whereas the carbon stored in lumber, plywood, or furniture will remain intact until the products are discarded and begin to decompose. As forest stands are harvested, the carbon stored in final wood products must be accounted for or the accounting process from the harvest will overestimate the amount of CO_2 released into the atmosphere. These carbon pools are referred to as **harvested wood products** (HWPs).

Photo Credit: Paul Hudgins, AFC

During a harvest operation, the forest landowner, logger, or wood-using facility is credited with stored carbon contained within the harvested roundwood. Who gets the credit depends on who has legal rights to the roundwood once severed and removed from the harvest site. This should be identified in the timber sale contract.

The DOE Guidelines allow two approaches to estimate the amount of carbon stored in harvested wood products. The **first approach** is to estimate the decay of materials stored in wood products over time so that the resulting emissions are accounted for in the year in which they occur. This requires entities to report annually an estimate of the decline in the carbon stored in the wood products produced, and is not used in these procedures because it is overly burdensome.

This **second approach** would allow an entity to report in the year that the harvest occurs the amount of carbon expected to remain in the harvested wood products after a 100-year period. Though a more liberal emissions amount, this approach is simpler and will be used in these procedures.

The following formula should be used to estimate the carbon stored in the harvested wood products 100 years after harvest:

Carbon Stored in Harvested Wood Products =

Weight of Carbon Harvested x 100-year Carbon Residual Percentage

The following table shows the 100-year carbon residual percentage of harvested carbon for Alabama and the general harvested roundwood categories, as found in DOE's guidelines.[8]

100-YEAR CARBON RESIDUAL OF HARVESTED ROUNDWOOD

ROUNDWOOD CATEGORY	100-YEAR CARBON RESIDUAL
	Residual % of Harvested Carbon
Softwood Pulpwood	**16.2 %**
Softwood Sawlog	**33.4 %**
Hardwood Pulpwood	**17.6 %**
Hardwood Sawlog	**28.5 %**

THE FOLLOWING STEPS SHOULD BE USED TO DETERMINE 100-YEAR RESIDUAL CO_2 FROM HARVESTED ROUNDWOOD:

STEP 1: DETERMINE GREEN TONS HARVESTED. Use forest inventory or scale tickets from harvest operation to determine green short tons of roundwood harvested by roundwood category.

STEP 2: CONVERT TO DRY METRIC TONNES OF CARBON DIOXIDE EQUIVALENT. Use the procedures previously presented to convert green tons determined in **Step 1** to dry tons of carbon dioxide equivalents **($MTCO_2e$)**.

STEP 3: CALCULATE HARVESTED WOOD PRODUCTS SEQUESTRATION. Multiply amount obtained in **Step 2** by the 100-year carbon residual factor. Sum totals by all roundwood categories.

EXAMPLE: ESTIMATE 100-YEAR RESIDUAL CO_2 FROM HARVESTED ROUNDWOOD

STEP 1: Continuing from the previous example, at the end of five years, the landowner decides to clearcut the 85-acre pine-hardwood stand. Scale tickets from the harvest operation show the following volumes were removed from the tract: 901 cords of pine pulpwood, 320 MBF (Scribner) of pine sawtimber, 500 cords of hardwood pulpwood, and 140 MBF of hardwood sawtimber (Doyle).

STEP 2: Weights obtained in **Step 1** are converted to dry metric tonnes of CO_2 equivalent as follows:

Pine Pulpwood: 901 cords	➔ 2,414 $MTCO_2e$
Pine Sawtimber: 320 MBF	➔ 2,403 $MTCO_2e$
Hardwood Pulpwood: 500 cords	➔ 1,452 $MTCO_2e$
Hardwood Sawtimber: 140 MBF	➔ 1,226 $MTCO_2e$

continued on next page . . .

[8] *DOE's Section 1605(b) Technical Guidelines for Voluntary Reporting of Greenhouse Gas Program. Part I Appendix Forestry. Table 1.6 Average disposition patterns of carbon as fraction in roundwood by region and roundwood category*. The guidelines *also allow for two alternative approaches to estimating 100 year residual carbon, one based on the harvested roundwood removed and the other on the finished wood products produced. Because this publication was produced with the forest landowner in mind, the following procedure using the harvested roundwood removed will be used. Forest industries wishing to report carbon dioxide sequestration amounts stored in produced finished products should refer to DOE's guidelines on the reporting procedures to use.*

STEP 3: The $MTCO_2e$ weights calculated in **Step 2** are then multiplied by the 100-year carbon residual factors to obtain an estimate of the CO_2 stored in harvested wood products, as shown in the following table.

Roundwood Category	Harvested CO_2	100-year Carbon Residual	CO_2 Sequestered in Harvested Wood Products
	-------------	$MTCO_2e$ on 85 acres harvested	-------------
Pine Pulpwood	2,414	x 0.162 =	391
Pine Sawtimber	2,403	x 0.334 =	803
Hardwood Pulpwood	1,452	x 0.176 =	256
Hardwood Sawtimber	1,226	x 0.285 =	349
TOTAL	**7,495**		**1,799**

In this example, 7,495 $MTCO_2e$ was harvested in the fifth year, which is exactly what was projected in the growth estimates (of course this will usually not happen in real situations). Of that harvested amount, 1,799 $MTCO_2e$ is retained in harvested wood products and the remaining 5,696 $MTCO_2e$ is emitted back into the atmosphere.

ACCOMPANYING CARBON TRACKING WORKSHEETS

To be developed …