CLIMATE
ACTION
RESERVE

Urban Forest Project Reporting Protocol

Version 1.0

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Table of Contents

1 Introduction

The Climate Action Reserve's Urban Forest Project Reporting Protocol provides guidance to account for and report greenhouse gas (GHG) emission reductions associated with a planned set of tree planting and maintenance activities to permanently increase carbon storage in trees.

The California Climate Action Registry (California Registry) is a leading source of accurate, transparent, and credible GHG accounting standards for reporting entity-wide GHG emission inventories. The California Registry also applies its knowledge and expertise in GHG accounting to the quantification of GHG emission reductions associated with specific project activities, to ensure the environmental integrity of programs based on these data and to support international efforts to combat climate change. Through its Climate Action Reserve program (the Reserve), the California Registry supplies protocols such as this one for quantifying GHG emission reductions (or offsets). In addition, it oversees and accredits independent third-party verifiers, and provides a web-based publicly accessible offset registration, serialization, and tracking service.

Project developers that implement tree-planting programs use this document to register GHG reductions with the Reserve. It provides eligibility rules, methods to calculate reductions, performance monitoring instructions, and procedures for reporting project information to the Reserve. Additionally, all project reports receive annual, independent verification by Reserve-approved verifiers. Guidance for verifiers to certify reductions is provided in the corresponding Urban Forest Project Verification Protocol.

Document Organization

The Urban Forest project protocol has the following sections:

- The GHG Reduction Project
- Project Eligibility
- The Project Boundary
- GHG Assessment Boundary
- GHG Reduction Calculation Methods
- Permanence
- Co-Benefits and Negative Impacts
- Project Monitoring
- Reporting Parameters
- Glossary of Terms

Project developers that follow the guidance in this protocol and register GHG reductions with the Reserve must comply with all local, state, and federal tree planting, air and water quality regulations.

To register GHG reductions with the Reserve, project developers are not required to prepare and submit an annual entity-level GHG inventory.

2 The GHG Reduction Project

Increasing levels of carbon dioxide and other greenhouse gases (GHG) in the atmosphere are of growing concern globally and locally, and urban forests have a role to play in the fight against climate change. Urban forests can reduce atmospheric carbon dioxide (CO_2) directly and indirectly. As long as trees are growing, they remove CO_2 from the air in a process called carbon sequestration, transforming CO_2 into carbon and making use of it to build living matter—leaves, stems, trunk, roots. GHG tree projects that account for the net storage of CO_2 through tree plantings can be reported and registered with the Reserve using this Protocol.

Urban forests have two additional, indirect effects on atmospheric CO_2 and other greenhouse gases (e.g. methane, nitrous oxide). First, trees around buildings can reduce heating and air conditioning use (Abdollahi et al. 2000), thereby reducing emissions of GHGs associated with the consumption of electricity, natural gas, and fuel oil. Second, normally when trees die, the stored carbon is released into the atmosphere through decomposition. However, if the biomass from removed trees is used as feedstock for power plants, GHG emissions that would have occurred with other fuel sources are displaced. These indirect benefits may be quantified and reported as co-benefits to the GHG tree project. However, the Reserve does not issue Climate Reserve Tonnes (CRTs) for indirect GHG emission reductions.

For a more detailed explanation of the role trees play in climate change and how to select and strategically locate trees to maximize GHG benefits, see Appendix A.

2.1 Project Definition

For the purposes of this protocol, an urban forest GHG project is a planned set of tree planting and maintenance activities to permanently increase carbon storage, taking into account GHG emissions associated with planting and maintenance of project trees.

While project trees are planted for the purposes of the urban forest GHG project, tree sites are the primary unit of analysis. A tree site contains one tree at a time, however the tree may be replaced over time and the site itself may be moved. This is because project trees themselves are subject to mortality and other types of losses and therefore may need to be replaced and/or relocated during the project lifetime (see Section 7 Permanence for details).

Tree plantings should have an average spacing of no less than 5 meters (biomass equations for estimating carbon stock changes are for open-growing urban trees and assume relatively intensive management). The spatial location of all project tree sites must be known and recorded (e.g. using GPS). For forest management and conservation activities that occur on large forested tracts within cities (≥ 100 acres contiguously forested), the Forest GHG Protocols should be used.

An entity can assemble several smaller projects into a single project for the purposes of achieving economies of scale and more efficient reporting. (Experts estimate that a project with at least 1,000 project tree sites will benefit from economies of scale). However, reporting, monitoring, and verification practices must follow the Reserve's guidance.

In addition to GHG benefits related to carbon storage, project developers may choose to report a project's emission reductions related to energy conservation and use of tree residue as a bioenergy feedstock as co-benefits (see Section 8 Co-Benefits). However, such benefits will not be included in the quantification for the issuance of CRTs for the project.

This protocol is applicable to three specific project types: Urban Forest GHG Projects undertaken (1) in Municipalities[1], (2) on Educational Campuses[2], and (3) by Utilities. A project is defined by a specific number of project tree sites, determined a priori, that will be planted and maintained within one of the above types of entities over the project lifetime. If, in the future, the entity wishes to plant more project tree sites than the number defined under the original project, this constitutes a second, distinct urban tree project. Entities can undertake as many urban tree projects as desired in the future as long as they each, separately, meet the eligibility criteria and reporting requirements in this protocol.

2.2 The Project Developer

The project developer can be a municipality, educational institution, utility, and/or a person or organization partnering with any of these entities. As specified above, an urban forest project must take place within one of the three designated types of entities. However, responsibility for tree planting, care, and maintenance activities may reside with the entity or a partner organization/individual, or it may be shared between both. In any case, the roles and responsibilities of the entity and the partner must be specified. In addition, ownership of the GHG reductions must be specified and documented a priori.

3 Eligibility

Project developers using this protocol must satisfy the following eligibility rules to register reductions with the Reserve. These criteria only apply to projects that meet the definition of a GHG reduction project as defined in this protocol.

3.1 Additionality

The Reserve strives to support only projects that yield surplus GHG reductions, which are additional to what might otherwise have occurred. That is, the reductions are above and beyond business as usual – the baseline case. Project developers satisfy the “additionality” eligibility rule by passing two tests:

1. The Performance Standard Test; and
2. The Regulatory Test.

The Performance Standard Test

Project developers pass the Performance Standard Test by meeting a program-wide performance threshold – i.e. a standard of performance applicable to all urban forest projects. A performance threshold value is determined by analysis of trends to represent “better than business as usual.” If the project exceeds the threshold then it exceeds what would happen under the business as usual scenario and generates surplus/additional GHG reductions. Past performance of individual urban forest projects is not used to

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[1] Including cities, counties, and other local agencies or special districts

[2] As noted in Section 4.1, the physical area owned and/or controlled by the entity determines entity boundaries. In the case of educational campuses, the project developer may define the entity as a single campus or a system of campuses, as long as the definition is clearly stated and the entity can demonstrate that it has ownership and/or control over the physical area.

determine business as usual; rather, business as usual is established from an assessment of urban forestry programs as a class.[3]

For this protocol, the Reserve uses a practice-based threshold, which represents “best practice standard” for urban forest tree planting programs. The project must demonstrate that it will exceed the performance threshold and information confirming this, in accordance with the guidance below, must be provided in the project submittal form.

The Reserve evaluated three separate Performance Thresholds, one for each type of entity in which a project can be implemented, based upon an analysis of data from municipalities, educational campuses, and utilities with tree planting programs in the United States. A summary of the data sets and performance threshold determinations is provided in Appendix E.

The performance threshold comparison is based on information for the entity within which the project will take place. If a partner organization/individual working with a municipality, educational campus, or utility plants trees outside the project boundary, these activities should not be included in the performance threshold comparison.

Municipalities and Educational Campuses

The performance thresholds for municipalities and educational campuses are measured in terms of net tree gain (NTG), i.e., the annual number of trees planted by an entity minus the annual number of trees removed by an entity. Only project activity that exceeds the performance threshold can be registered.

Based on data from high-performing municipal and educational campus entities, the performance threshold has been set at maintaining a stable urban forest population, i.e., entities must plant at least as many trees as they remove, or a NTG of 0. (For more information on how the performance threshold was determined, see Appendix E.)

A project developer must demonstrate a priori that a project will exceed the threshold by calculating the anticipated NTG of the entity based on recent entity activities and anticipated project activities. Specifically, the calculation must be based on:

1. The annual average number of urban trees planted and removed in the entity over no more than the most recent five year period proceeding the project start date, or using data from a single year occurring at some point during the past most recent five year period.

2. The expected average annual number of GHG project tree sites to be planted by the project.

3. Where, urban trees include trees under the entity’s ownership or control and are open-grown in managed landscapes.

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[3] The Reserve will not be evaluating past performance of any individual project to determine business as usual. However, information on individual urban forest programs is used to compare project performance to the performance threshold. By using this approach, the Reserve invests in developing standardized criteria upfront that is used consistently by all project developers. This reduces initial transaction costs to project developers and provides for efficient and consistent project evaluation.

For each year of the project, the developer will be required to report an annual average NTG (number of urban trees planted minus removed) for the entity, including regular entity activities (planting of “non-project” trees) and project activities (planting of “project” trees). The annual average NTG must be based on a five-year rolling average (i.e. the most recent previous five years including the reporting year), except in the first five years of the project when the average may be based on less than five years of data (i.e. one-year average in the first year of the project, two-year average in the second year, and so on). When the average annual NTG for the entity is positive (more trees are planted than removed), the number of trees planted in excess of the number removed determines how many eligible project trees can be designated that year. Specific eligible project trees are identified each year by the project developer and tracked individually for the duration of the project. Carbon sequestration and GHG emissions from tree care, monitoring, and maintenance of the eligible project trees are the basis for calculating GHG reductions.

If the entity reports a negative NTG in any given year, no new trees planted that year can be considered eligible project trees and no GHG reductions can be registered. When the entity returns to an average annual NTG of zero or greater, GHG reductions from project trees during the intervening years (up to a maximum of five years) can be registered ex post, as long as the criteria in this protocol for project trees were met during those years.

Utilities

Review of existing data determined that most utilities do not have tree planting programs that go beyond replacing trees removed during line clearance operations. While some have programs specifically aimed at storing carbon and conserving energy in residential households, on average utilities are planting fewer than 400 trees annually in these types of programs (see Appendix E for details).

Because it is not common practice for utilities to have residential tree planting programs, all trees planted under these types of programs are considered additional and therefore are designated as eligible project trees. These trees may be used to generate GHG emission reductions, provided all criteria in this protocol are met.

The Regulatory Test

The Reserve subjects all greenhouse gas reduction projects to a regulatory test to ensure that the emission reductions achieved would not have occurred in the absence of the project due to federal, state or local regulations. Urban Forest GHG Projects must also exceed any applicable regulations or statutes. Examples include municipal ordinances that require street, park, and parking lot tree planting or local mitigation requirements imposed on a project. Local codes, covenants, and restrictions may require tree planting to buffer adjacent land uses or for other purposes. State laws may prescribe minimum levels of tree planting for energy conservation and other reasons. Trees that are planted to comply with regulatory requirements may not be considered project trees.

3.2 Location

Project developers may report projects within California or any other part of the nation. Project tree sites must be located according to guidance in Section 2.1 Project Definition (average spacing of no less than 5 meters) and Section 4 The Project Boundary (e.g.

along streets, in parks and parking lots, etc.). Thus, Urban Forest Projects are likely to take place in urban or other types of developed areas.

3.3 Project Start Date

California Senate Bill 1771 (Sher) created California Registry in September of 2000 to serve as a platform to record and register GHG reduction activities, among other things. This sent a signal to GHG-emitting entities that project activities could receive recognition for their carbon value. The establishment of California Registry to support GHG reduction activities is the basis for the project start date criterion. All GHG reduction projects that implement a planned set of tree planting activities are eligible to register reductions with the Reserve if the system started operating on or after January 1, 2001 (and the project meets all other eligibility requirements). Projects that began operating before January 1, 2001, are not eligible to register reductions according to this protocol. For the Reserve's purpose, the commencement of operation means when trees are planted and regular maintenance begins.

4 The Project Boundary

The Project Boundary outlines the components of the project operations that are impacted by the project activity, including the physical area covered by the project as well as the specific equipment used by the project. In this protocol, the project boundary includes:

- The number of eligible project tree sites (determined in Section 3); and
- Equipment used to plant and maintain the trees.

Tree sites must be located within the boundary of an entity (i.e. a municipality, educational institution, or utility). Entity boundaries are determined by the physical area owned and/or controlled by a municipality or educational campus, or the service area covered by a utility.

For each project type, eligible project trees must be planted:

- Along streets, in parks, city golf courses, cemeteries, near city buildings, greenbelts, city parking lots, and other public open space, or on private property in municipalities;
- Along streets, near classrooms, dorms, office buildings, near recreational fields and other facilities, in parking lots, arboretums, and other open space on educational campuses; and
- In parks, streets, parking lots, private property, and open spaces by utilities.

5 GHG Assessment Boundary

The GHG Assessment Boundary delineates all relevant GHG sources, sinks and reservoirs that are considered significantly affected by the project activity and must be included in the calculation of GHG reductions.

In this protocol, the GHG Assessment Boundary is defined as the carbon stored in standing trees and GHG emissions from motor vehicles and equipment used in tree care activities.

Other carbon pools, such as shrubs, woody debris, and soil are not reported at this time. Although there is some research quantifying the movement of carbon through these pools, it is difficult to model, measure, and verify how tree planting projects change these carbon pools (Groffman et al. 2006, Kaye et al. 2005; Pouyat et al. 2002). Carbon stored in harvested wood products (HWP) from urban trees is not reported at this time because the quantification methods are complex and only relatively small increases in HWP carbon are anticipated from urban tree projects.

While the GHG Assessment Boundary delineates the GHG sources and sinks that must be reported, optional GHG sources and sinks are also noted below and can be reported as co-benefits.

Required and optional GHG source and sink categories for reporting are as follows:

- Carbon storage in standing trees – mandatory.
- GHG emissions from motor vehicles related to tree planting, care, and monitoring – mandatory.
- GHG emissions from equipment related to tree planting and care – mandatory.
- Reduced GHG emissions from energy conservation – optional.
- Displaced GHG emissions from bioenergy – optional.

Carbon dioxide (CO_2) is the primary GHG to report for urban forest projects. Methane and nitrous oxide emissions from tree planting and care do not need to be reported at this time because these emissions are considered to be de minimis.

5.1 Leakage

Leakage is an increase in GHG emissions or decrease in sequestration caused by the project but not accounted for within the project boundary. In the case of urban forest projects, the most likely form of leakage is the shifting of funds and maintenance from non-project tree resources (i.e. trees within the entity that are not part of the project) to project trees within an entity. For example, if funding is reduced for pruning existing trees to fund a GHG tree planting project, there may be an overall decline in the health of the urban forest within an entity and a long-term increase in mortality. A tree maintenance plan (TMP) is used to assess whether this type of activity-shifting leakage is occurring. Details on the TMP requirements are provided in Section 9 Project Monitoring. If annual expenditures of the entity (separate from project expenditures) in one or more program areas decrease by more than 10% from amounts in the initial TMP or from amounts in the previous year TMP, and these changes cannot be explained by the project developer, leakage will be assumed and if confirmed, no carbon reduction can be registered in that year.

Market leakage is less likely in urban forestry. Market leakage involves the modification of the overall timber market as a result of the implementation of a project. Because there is little market for urban forest products and because the investment that entities have made in urban trees is generally greater than any market value, this type of leakage is considered unlikely and therefore negligible in this protocol.

6 GHG Reduction Calculation Methods

This section provides the detailed methods for calculating emissions and removals from the mandatory GHG sources and sinks reported annually to the Reserve:

- Carbon storage in standing trees: *Annual Project CO_2 Sequestration*
- GHG emissions from motor vehicles related to tree planting, care, and monitoring: *Annual Vehicle CO_2 Emissions*

- GHG emissions from equipment related to tree planting and care: *Annual Equipment CO_2 Emissions*

Project GHG reductions are based on the amount of carbon sequestered in eligible project trees annually minus GHG emissions from the annual planting, care and maintenance of those trees. Below is the general formula for determining annual project GHG reductions.

$$\text{Annual Project GHG Reductions} =$$

$$\text{Annual Project } CO_2 \text{ Sequestration} - \text{Annual Vehicle } CO_2 \text{ Emissions} - \text{Annual Equipment } CO_2 \text{ Emissions}$$

6.1 Quantifying Project CO_2 Sequestration

Each year, the project developer estimates the amount of carbon stored in eligible project trees (carbon stocks) and then uses these data to calculate an annual incremental carbon stock change (carbon sequestration). Carbon stocks are reported in units of carbon dioxide equivalent. The annual change in carbon stocks is the basis for estimating project carbon sequestration.

$$\text{Annual Project } CO_2 \text{ Sequestration} = CO_2 \text{ stock}_{\text{year } x} - CO_2 \text{ stock}_{\text{year } x\text{-}1}$$

Quantifying Tree Carbon Stocks

There are three approved approaches to quantifying the annual carbon stocks in eligible project trees, each of which is based on direct measurements of trees and approved urban tree carbon models ("allometric equations"). Consult Appendices B, C, and D for detailed guidance on implementing the approaches.

Appendix B covers how to design tree measurement programs ("inventories"), including required tree measurement data, and sampling techniques, design, and error. Appendix C describes how to estimate tree carbon from tree measurement data using allometric equations and how to use these same equations to predict biomass when measurement data are not available. Appendix D describes a calculation tool, the Center for Urban Forestry Research (CUFR) Tree Carbon Calculator (CTCC) that can also be used to estimate tree carbon.[4] The CTCC tool is based on well-developed urban tree allometric equations.

Approved Approaches for Quantifying Carbon Stocks:

1. Measure all trees in project tree sites during a single year at 10-year intervals. Use the measurement data with approved allometric equations (Appendix C) or the CTCC (Appendix D) to estimate carbon stocks. In the intervening years when you do not implement measurements, use approved methods to predict annual carbon stocks (Appendix C or D). Such methods employ growth assumptions and allometric equations to estimate carbon stocks and are referred to below as growth models.

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[4] The CTCC tool is currently in the final stages of development by CUFR. As soon as possible, it will be made available online (anticipated in Fall 2008).

Direct tree measurements or remote sensing techniques may be used. Data from direct tree measurements (i.e. tree diameter at breast height) can be input directly into approved allometric equations. Remote sensing can be used to estimate tree crown area, from which tree trunk diameter is inferred.[5]

2. Measure all trees in project tree sites every 10 years using a rolling sample, which means a minimum of 10% of the tree sites are measured each year and after 10 years you have measured 100% of your tree sites (Appendix B). Use the measurement data with approved allometric equations (Appendix C) or the CTCC tool (Appendix D) to estimate carbon stocks. For trees that are not measured in a given year, use approved methods ("growth models") to predict annual changes in carbon stocks (Appendix C). As described above in Approach 1, direct measurement or remote sensing techniques[5] may be used to estimate tree carbon stock (Appendix B). Remote sensing may also be used to identify project tree sites for sampling.

3. Measure a sample of trees in your project tree population each year (Appendix B), use the measurement data with approved allometric equations or the CTCC tool to estimate carbon stocks in your samples (Appendix C and D), and extrapolate the carbon stock estimates to the entire tree population (Appendix B). As described above in Approach 1, direct measurement or remote sensing techniques[5] may be used to estimate tree carbon stock (Appendix B). Remote sensing may also be used to identify project tree sites for sampling.

Requirements for Tree Monitoring and Acceptable Levels of Uncertainty

A Tree Monitoring Plan must be included in the project submittal form (see Section 10 Reporting Parameters for details). The Tree Monitoring Plan must describe in detail the approach the project plans to use to quantify carbon stocks. The document will serve as guidance for the project developer and will communicate the methodology to the verifier. The verifier will determine if the methodology is acceptable according to the verifier protocol. A verifier must approve the Tree Monitoring Plan before the project can begin reporting.

Approaches 1 and 2 both employ growth models where measurements that were performed in previous years are updated using growth models to estimate carbon stocks for a particular reporting date. For example, a tree measured five years previously will need to be 'grown' to estimate its carbon stocks in the current reporting year. When this approach is used, the estimate is considered as reliable as using a current tree measurement, provided the growth model used is approved (see Appendix C and D), no measurement is 'grown' with a growth model for more than 12 years, and the growth assumptions are validated during the first five years of the project using actual tree measurements following the guidance below.

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[5] Pre-approved regression equations must be used to convert tree crown diameter (or crown projection area) to tree diameter. The U.S. Forest Service Center for Urban Forestry Research (CUFR) is in the process of developing regression equations for common street tree species in each of 16 U.S. regions. When these become available, they can be used as pre-approved regression equations. Until then, the Reserve will not accept estimates based on remote sensing data.

Actual tree growth may differ significantly from tree growth models. Therefore, it is important to quantify, assess, and fix differences at the beginning of the project through monitoring of actual tree growth. When using growth models, monitoring over the first five years of the project must be conducted to validate and, if necessary, calibrate growth models, such that carbon stock estimates from growth models do not differ by more than 10% from carbon stock estimates using tree measurements. Growth models must be validated and recalibrated every 10 years thereafter throughout the lifetime of the project.

Before using the approved growth models, consider contacting local arborists and other tree experts (e.g. local university extension offices, city tree managers) to evaluate the growth assumptions. Obtaining information on “typical” annual growth is important – whether a species normally grows 1 cm per year or 3 cm per year is helpful. If arborists can provide average annual growth (in diameter at breast height, “dbh”) when trees are young, adolescent, middle-aged and senescent, these data can allow for further comparison with data produced by the CTCC.

Approach 3 involves statistical extrapolation from sample data. The sampling method must be stratified by like species and age classes (not to exceed groupings of five-year age classes). The combinations of species and age classes create independent sampling populations, or strata. Appendix B provides further details on stratified sampling design.

The resulting estimates must meet a minimum confidence level of 90% to register all of the estimated carbon stocks. If the project sampling design results in lower levels of confidence, the carbon stock estimates will be discounted according to the guidance below. See Appendix B for details on how to design a robust sampling program that will meet the desired level of confidence.

Descriptive statistics must be produced at the time of verification if a sampling methodology is incorporated. The estimate of carbon stock change in project trees is adjusted based on the level of confidence in the estimate according to the table below. The table provides sampling error ranges (where sampling error is on either side of the mean estimate at the 90% confidence level), calculated with the following equation:

*Sampling Error (90% confidence interval) = (1 Standard Error *1.645)*

Sampling Error*	**Carbon Stock Change Adjustment (deduction by)**
0 to 5%	0%
5.1 to 10%	10%
10.1 to 15%	20%
15.1 to 20%*	30%
> 20%	100%

*Minimum Confidence Interval at 90% confidence limits.

6.2 Quantifying GHG Emissions from Motor Vehicles Related to Tree Planting and Care

Vehicle emissions are those associated with transport of personnel, supplies, and trees to and from eligible project tree sites. The methods below are consistent with those provided in the California Registry General Reporting Protocol (GRP) for mobile combustion emissions.

- Calculations of CO_2 emissions from vehicles are based on actual fuel use (gallons per year) and an emission factor (kg CO_2 per gallon) for fuel. The amount of fuel used for the eligible project trees can be estimated by prorating total fuel usage for all tree maintenance and monitoring activities in the entity by the number of eligible project tree sites relative to total entity trees.

$C_{\text{vehicle emis}} = (TC_g \times EF_g) + (TC_d \times EF_d)$

where TC = total annual fuel consumption (gallons) of gasoline (TC_g) or diesel fuel (TC_d) and EF = fuel emission factor ($EF_g = 8.81$ kg CO_2 per gallon of gasoline or $EF_d = 10.15$ kg CO_2 per gallon of diesel fuel). Divide by 1,000 to convert kilograms into metric tons (t). See the GRP, Appendix Table C.4 for CO_2 emission factors for additional fuel types if applicable (e.g., biodiesel or ethanol).

- Where actual fuel use (TC) is not available, it can be estimated using vehicle information (make, model, fuel type, and model years) and annual mileage estimates by vehicle type. Convert annual mileage to fuel consumption using EPA's fuel economy formula (see Eq. III.7b in the GRP).

6.3 Quantifying GHG Emissions from Equipment Related to Tree Planting and Care

Equipment emissions are associated with back hoes used in planting, and chain saws, aerial lifts, and chippers used during tree removal and pruning activities.

1. If the total amount of fuel consumed by equipment on GHG project-related activities is known, CO_2 emissions can be calculated using fuel-specific emission factors as above.

   $C_{\text{equip emis}} = (TC_g \times EF_g) + (TC_d \times EF_d)$

2. In many cases, however, equipment use is tracked in hours. If the hours are known, the emissions can be calculated for each piece of equipment based on the following formula and then summed:

   $C_{\text{equip emis}} = HRS \times LF \times HP \times EF$

   where HRS = hours used, LF = typical load factor, HP = maximum horsepower and EF = average CO_2 emissions per unit of use (kg/hr). Typical load factors, horsepower, average emissions, and EFs for equipment are given in Table 1. Typical hours required for pruning and removal activities are given for maintenance equipment in Table 2.

Table 1. Typical load factors (LF) and average CO_2 emissions (EF) for different maintenance equipment.

Equipment	LF [a]	EF (kg/hp/hr)[b]	EF
Aerial lift (45 hp)	0.505	0.783	0.568
Backhoe	0.465	0.775	0.568
Chain saw (2 hp)	0.500	0.429	0.568
Chain saw (7 hp)	0.500	0.429	0.568
Chipper (50 hp)	0.370	0.783	0.568

[a] Nowak et al. 2002
[b] CARB 2008

Table 2. Total hours of equipment run-time by dbh classes (inches) for tree pruning and removal (from ACRT data as cited by Nowak et al. 2002). Assumes crews work efficiently and equipment is not run idle.

	Pruning				Removal				
dbh	2.3-hp saw	3.7-hp saw	Bucket truck[a]	Chipper[b]	2.3-hp saw	3.7-hp saw	7.5-hp saw	Bucket truck	Chipper
1-6	0.05	NA	NA	0.05	0.3	NA	NA	0.2	0.1
7-12	0.1	NA	0.2	0.1	0.3	0.2	NA	0.4	0.25
13-18	0.2	NA	0.5	0.2	0.5	0.5	0.1	0.75	0.4
19-24	0.5	NA	1.0	0.3	1.5	1.0	0.5	2.2	0.75
25-30	1.0	NA	2.0	0.35	1.8	1.5	0.8	3.0	1.0
31-36	1.5	0.2	3.0	0.4	2.2	1.8	1.0	5.5	2.0
36+	1.5	0.2	4.0	0.4	2.2	2.3	1.5	7.5	2.5

[a] Mean HP = 43 (U.S. EPA 1991)
[b] Mean HP = 99 (U.S. EPA 1991)

If in planning for an urban tree project, a project developer wishes to forecast emissions from vehicles and equipment used in tree planting, a value of 2.62 kg CO_2 per project tree per year (McPherson and Simpson 1999) can be used. Divide by 1,000 to convert kilograms into metric tons (t). Projected values may not be used when reporting annual project GHG reductions, but may be useful for project planning.

7 Permanence

GHG projects involving biological carbon sequestration must address the potential reversibility of sequestered carbon, or more precisely the loss of stored carbon after carbon benefits have been reported, verified, and registered. Consistent with guidance from the Intergovernmental Panel on Climate Change, the Reserve's underlying standard for permanence is a minimum of 100 years—the biological carbon should remain stored for 100 years (e.g. a reduction of carbon created in 2008 will remain stored until 2108 and if it is reversed, e.g. through mortality, then it must be replaced).

The Reserve expects project developers to take steps to maximize the likelihood that the carbon gains of urban forestry projects are preserved for this period of time or longer. To this end, the following are requirements of this protocol:

1. Continuous annual reporting of carbon stocks for a project lifetime of 100 years.

2. Continuous replacement of dead trees at all tree sites during the project lifetime (i.e. projects must have an average net tree gain of no less than zero). Dead trees must be replaced within one year from when they were removed. This timeframe allows for planting to occur at the appropriate time of year (e.g. loss and removal may occur in the fall and replanting occurs in the spring). Each tree site may have one or more replacement trees over time. Also, the location of some GHG tree project sites may change due to disturbances that unexpectedly eliminate tree sites. It is the developer's responsibility to promptly locate and plant replacement sites so that there is no reduction in the total number of treed project sites.

3. If reversals are not compensated for with replacement trees, they will have to be compensated for using another approved mechanism. The Reserve is developing flexible mechanisms to address reversals that will apply to all forest GHG protocols including this one.

Guidance to Understanding Risks of Reversals

To further assist project developers in identifying and minimizing risks of reversals, following is guidance to understanding risks of reversal.

Disturbance Potential: There are three main types of disturbances that influence the risk of future reversibility: land use change, human disturbance, and natural disturbance. Project developers should identify the potential risk each type of disturbance poses to their GHG tree project. Land use change refers to the likelihood of future changes in land use that threaten tree survival, such as zoning changes to more intensive land uses, new development, infill or redevelopment, and reconfiguration of transportation corridors. The risk of land use change will be least when tree planting sites are in easements guaranteed to remain undisturbed in perpetuity. The risk of land use change will be highest when tree sites are located in areas zoned or planned for future development and redevelopment.

Human disturbance potential concerns human-induced change resulting in tree mortality after carbon reductions have been certified. Human disturbance potential is defined as threats to tree survival that are not related to land use change. Examples include changes in management (e.g. ending irrigation and pest/disease treatment), increased vandalism, and changes in levels of air and soil pollutants or soil moisture. Human disturbance potential is least when tree species are tolerant of the most likely threats and the threats are relatively few and benign. Human disturbance potential is greatest when the tree species are intolerant of future stressors and those threats have potential to decimate large numbers of project trees.

Natural disturbance potential refers to threats to tree survival associated with non-human causes, such as disease, fire, drought, cold, ice/snow, wind/hurricane, flooding, earthquake, landslide, and volcano. The frequency (return interval) and severity of each type of natural disturbance influence its risk to the GHG project tree population. For example, tree sites within a 10-year flood plain will be at higher risk than sites outside this risk zone. In assessing risk, consider the relative tolerance of the tree species to the natural disturbances most likely to occur at the tree sites.

These risks of reversibility should be carefully assessed and addressed in the Initial Project Report. Locating tree sites and selecting species that minimize the risk of loss from disturbance will increase the project's long-term success. Measures taken to reduce the risk of tree loss due to disturbances should be explained.

Project Resources: The Reserve encourages project developers to describe project resources that improve its robustness. Examples of project resources include management capacity, financial capacity, future income, project endorsement, and proven technologies/practices. Project developers should ensure that long-term maintenance and tree care programs are in place, proper organizational and/or legal frameworks exist to support project activity, and sufficient financial resources are present to support the project and provide for monitoring.

Project Activities: Project developers should also include as part of their permanence reporting a description of activities taken to promote establishment, vigorous growth, and longevity of project trees. Examples include purchasing trees grown to quality standards, providing effective training in tree care practices, enforcing ordinances to protect project trees, and implementing tree care agreements.

8 Co-Benefits and Negative Impacts

Urban trees may have GHG benefits in addition to those from sequestration. Trees planted strategically to reduce energy use will effect reductions in GHG emissions at the power plant. Tree residue used as fuel in bioenergy plants may effect reductions in GHG emissions if the trees are used to replace fossil fuel sources, such as coal. Specific guidance is provided in Appendix F for estimating these indirect GHG emissions reductions from energy conservation and bioenergy production. Reporting forms include fields for the optional reporting of these and other co-benefits of GHG tree projects.

Tree planting and stewardship activities can provide other co-benefits, including air and stormwater quality improvement, controlling runoff, conserving water, conservation education, neighborhood revitalization, job training, and recycling green waste. U.S. Forest Service research indicates that when the economic value of benefits trees produce is assessed, total benefits can be two to six times greater than costs for tree planting and care (McPherson et al. 2005). Furthermore, many of these benefits extend beyond the site where a tree grows, to influence quality of life in the local neighborhood, community, and region. The value of the services provided by GHG project trees is likely to increase as the trees mature.

Urban forestry projects may have unintended consequences that adversely impact other efforts to promote sustainability and quality of life. Care should be taken during the project planning phase to identify and mitigate any potential negative impacts (i.e. choose appropriate tree species). Potential negative impacts could include: impacts on urban forest biological diversity (a variety of tree species should be planted to avoid a monoculture); threats from invasive plants/pests/disease; water resources – conservation and runoff management; air quality – net effects on air quality (biogenic volatile organic compounds, aeroallergens); infrastructure – root conflicts with sidewalks and curbs and gutters, trees in power lines, visibility of signage, add to sanitation and solid waste stream, etc.; energy – attenuation of solar access to dedicated solar systems. It is important to document these potential impacts and the measures taken by the project to avoid or mitigate such impacts.

9 Project Monitoring

Project developers are responsible for monitoring the performance of the project and maintaining records of monitoring data in accordance with the requirements stipulated in Section 10 Reporting Parameters. Monitoring requirements are divided into these categories:

- Tree Maintenance Plan,
- Tree Monitoring Plan, and
- GHG Emissions and Sequestration Activity Data.

The Tree Maintenance Plan is used to assess the potential of activity-shifting leakage and other aspects of project performance. The Tree Monitoring Plan and GHG Emissions and Sequestration Activity Data are used to verify GHG emissions and sequestration estimates.

9.1 Tree Planting, Maintenance, and Levels of Service

Reporting planting and maintenance activities and expenditures is critical to assessing leakage and GHG tree project compliance. At the entity level, by comparing reported annual tree care expenditures for different years one can assess if a boost in project activity coincides with a drop in the level of care non-project trees are receiving (i.e. activity-shifting leakage may be present). At the project level, information about tree maintenance and expenditures helps assess the strength of the project and its likelihood of success. In addition, entity-level tree planting and removal practices must be reported each year to determine the number of eligible project trees.

To standardize annual reporting of tree planting and maintenance operations, activities are grouped into five program areas: tree planting, young tree care (< 5 years), mature tree care (> 5 years), tree removal, and administration/other (e.g. clerical, training, outreach). Annual expenditures and the level of service provided are indicators for each program area. Level of service is a quantifiable measure of tree care activities performed during a year. Higher levels of service indicate greater amounts of work performed. Reporting entities must provide a tree maintenance plan (TMP) that describes entity-level expenditures for a 10- to 20-year period and project level activities for the reporting period.

Below are the specific TMP requirements. All information is for GHG project activities and expenditures (i.e. those related to project trees), except where noted. In some cases, information about the entity is also required to assess leakage potential (i.e. activities and expenditures related to non-project trees). Where both project and entity-level information is required, this is denoted in parentheses. Otherwise the information pertains to the project only.

Note that project developers must report on the most recent annual levels and expenditures and estimate the anticipated annual levels and expenditures for each of the criteria below in the Project Submittal Form and maintain records on actual levels and expenditures each year for the project lifetime.

Tree planting:

  - Number of trees planted in new tree sites each year, not including replacement trees (total for the entity, including project and non-project trees).
  - Number of trees planted to replace removed trees each year (“replacement trees”), including replacement trees planted in relocated tree sites (separately for non-project and project trees).
  - Species, size, and location* of project trees planted in new tree sites each year.
  - Species, size, and location* of project replacement trees planted in existing or relocated tree sites each year.
  - Number and location* of relocated project tree sites each year.
  - Reasons for relocations and, if applicable, modifications made to the project to reduce the chance of future relocations.
  - Project tree resource: percentage of total project tree sites now planted.
  - Annual tree planting expenditure (separately for the project and entity).

- Young tree care
  - Number of young project trees inspected/pruned each year.
  - Inspection/pruning cycle (total number of project trees / number treated per year).
  - Annual expenditure (separately for the project and entity).
- Mature tree care
  - Number of mature project trees inspected/pruned each year.
  - Inspection/pruning cycle (total number of project trees / number treated per year).
  - Annual expenditure (separately for the project and entity).
- Tree removal
  - Number of trees removed from existing tree sites each year (separately for non-project and project trees).
  - Species, size, and location* of project trees removed each year.
  - Reasons for removals and, if applicable, modifications made to the project to reduce the chance of future removals.
  - Removal cycle (total number of project trees to remove / number removed per year).
  - Annual expenditure (separately for the project and entity).
- Administration/other
  - Average $/tree site expenditure (total $ on admin and other / total tree numbers) (separately for the project and entity).
  - Annual expenditure (separately for the project and entity).

* Tree site location can be designated on a map of the project physical boundaries (see Section 10.1 Project Submittal Form for details).

If the potential for leakage is determined, the project developer will have the opportunity to explain changes in expenditures. Additional information on entity-level tree planting activities may be requested by the verifier.

9.2 Tree Monitoring Plan

A Tree Monitoring Plan is important for several reasons. The plan provides sufficient and transparent information on tree measurement and monitoring. This information is used to ensure the quantification methods meet the standards of this protocol. In addition, the plan informs the project about the status of trees sites, helping to ensure that lost trees are replaced and risks of reversals are minimized.

- Indicate the choice of method from the three options in Section 6.1.
- Detailed description of procedures to census, measure, and report information on the project trees, including the survey method (ground survey or remote sensing), sample sizes, and method for choosing samples.
- Methods used to measure and record tree size and growth.
- Methods used and information collected on tree survival and health.
- Growth assumptions, if applicable.
- Description of data used to validate growth assumptions, if applicable.
- Modifications made to improve growth assumptions, if applicable.
- Statistical methods used to extrapolate sample data to the total project tree population, if applicable.
- Estimated sampling error, if applicable.

9.3 GHG Emissions and Sequestration Activity Data

The data below are needed inputs for estimating project GHG reductions. Transparent reporting of this information enables verification.

- Data on the species, size, date of measurement, and location of measured trees.
- Specific equations used to calculate carbon storage, or specify if CTCC model was used.
- Annual amount and type of fuel used by tree planting and care vehicles (or the vehicle miles traveled and average fuel economy).
- Annual amount and type of fuel used in tree maintenance equipment (or the number of hours equipment is used that year).

10 Reporting Parameters

This section provides guidance on reporting rules and procedures. A priority of the Reserve is to facilitate consistent and transparent information disclosure among project developers.

Before registering reductions associated with urban forestry GHG projects, project developers prepare a Project Submittal Form to list a project. Then, project developers submit annual project reports through the Reserve's online registration software in which annual carbon sequestration in project trees and vehicle and equipment GHG emissions related to tree planning and care are reported.

10.1 Project Submittal Form

The following information will be requested in the Project Submittal Form.

General background information on the entity, partner (if applicable), and project:

1. Name of the project developer (reporter).

2. Name and legal standing of the entity.
3. Name of partner organization/person (if applicable).
4. Project start date.
5. Date of the initial reporting year.
6. Project lifetime: must be 100 years.
7. Location of the project

Project Summary:

1. State the GHG tree project's goals.
2. Describe any general guidelines that will inform project development and execution.
3. Person or Entity who is chiefly responsible for planning, implementation, and reporting of project activity. List and explain the involvement of partners, if applicable.
4. Provide documentation describing how ownership of GHG reductions will be determined.
5. Briefly describe implementation of the project. Include information on the number of project tree sites and trees that will be planted (including replacements), types of species, and where they will be planted, tree stewardship and monitoring plans. *Some of this information is also requested in the TMP described below.*
6. Confirm that the trees will be planted in maintained landscapes and spaced at least 5 m (16 ft) apart so as to be open growing.

Project Boundaries:

1. Describe and/or include a map of the physical boundary of the project, including anticipated tree sites, an outline of the entity boundary, and tree care facilities (location where vehicles and equipment are housed).
2. List the mandatory and optional GHG emissions sources and sinks that will be included in the GHG Assessment Boundary

Project Eligibility: Project Performance and Regulatory Screen:

1. Expected average annual number of project tree sites created over the project lifetime (same as project NTG).
2. Entity average annual NTG prior to the start of the project (municipalities and educational campuses).
3. Total number of entity trees prior to the start of the project (municipalities and educational campuses).
4. Describe tree planting requirements mandated by law and planned to be undertaken by the entity.

Description of Risk of Reversals:

1. Describe the chief threats to GHG project tree survival due to land use changes, and human and natural disturbances. Describe the measures that will be taken to mitigate and adapt to these threats.
2. Explain how factors such as management capacity, financial capacity, project endorsement, and proven technologies/practices will enhance the project's ability to ensure a 100 year standard for carbon sequestration.
3. Describe activities that will be taken to promote establishment, vigorous growth, and longevity of project trees, such as requirements for quality stock, mechanisms to ensure adequate training for planting and care, tree protection ordinances, and tree care agreements.

Co-Benefits and Negative Impacts:
1. Describe anticipated co-benefits and specify which if any will be quantified annually.
2. Describe measures that will be taken to prevent and mitigate potentially adverse impacts.

Tree Maintenance Plan:
1. Document most recent and anticipated future levels of service and expenditures for all criteria in the Tree Maintenance Plan (Section 9 Project Monitoring for details).
2. Describe how project tree planting sites will be identified and prioritized. Describe any guidance, performance requirements, or specifications related to quality of nursery stock, planting details, training for tree planters, and initial staking, mulching, watering.
3. Provide estimates of tree mortality rates for newly planted and established project trees and explain how these numbers were established.
4. Describe how project trees that need replacing will be identified, how quickly they will be replaced, and size and species of replacement trees.
5. Identify the personnel who will implement and manage the project, their roles and responsibilities, and funds required for salary, operations, training, and overhead over the lifetime of the project. Other activities that may be included here are public relations, accounting, fund raising, and outreach.

Tree Monitoring Plan

Provide a detailed description of:
- Method (chosen from the three options in Section 6.1).
- Procedures that will be used to census, measure, and report information on the project trees, including the survey method (ground survey or remote sensing), sample sizes, and method for choosing samples.
- Methods that will be used to measure and record tree size and growth.
- Methods that will be used and information collected on tree survival and health.
- Growth assumptions that will be use, if applicable; and information supporting the choice of assumptions.
- Description of plans to validate growth assumptions, if applicable.
- Statistical methods that will be used to extrapolate sample data to the total project tree population, if applicable.
- Estimated sampling error, if applicable.

10.2 Record Keeping

For the purposes of independent verification and historical documentation, project developers are required to keep all information outlined in this protocol for a minimum of seven (7) years post project verification.

10.3 Reporting Cycle

For the purposes of this protocol, project developers report GHG reductions associated with planned tree planting activities that occurred the preceding year. In keeping with the reporting rules of California Registry's General Reporting Protocol, the reporting deadline for project developers is June 30 the year following the reduction year, and the verification deadline is October 31.

10.4 Project Crediting Period

Project developers are eligible to register GHG reductions with the Reserve according to this protocol for a period of 100 years.

10.5 Non-California Climate Action Registry Reporting

The California Registry requires that project developers only register reductions from GHG reduction projects with one registry. Upon submittal of verified GHG reductions to the Reserve, project developers are required to provide a signed attestation stating that the GHG reductions being registered are not being registered elsewhere. If the Reserve determines that duplicative emissions reductions registration has occurred, registration of the project will be cancelled and the project developer precluded from registering any other projects.

11 Glossary of Terms

Activity-shifting leakage	Shifting of activities or resources from other parts of the entity to the project, causing unanticipated increases in GHG emissions outside the project boundary.
Additionality	Greenhouse gas emission reductions should occur as a result of specific GHG mitigation incentives; additionality is achieved when GHG reductions are beyond what would occur under "business as usual."
Baseline	An estimate of GHG emissions and removals that would have occurred under business as usual.
Biomass	The amount of living matter comprising, in this case, a tree.
Carbon pool	A reservoir that has the ability to accumulate and store carbon or release carbon. In the case of forests, a carbon pool is the forest biomass, which can be subdivided into smaller pools. These pools may include above-ground or belowground biomass or roots, litter, soil, bole, branches and leaves, among others.
Climate Reserve Tonne (CRT)	One metric ton of verified CO_2 equivalent emission reduction or sequestration (pronounced "carrot").
Carbon sink	A carbon sink is any process, activity or mechanism that removes carbon dioxide from the atmosphere.
Carbon source	A carbon source is any process or activity that releases carbon dioxide into the atmosphere.
Carbon stock	A pool of stored carbon. Forest carbon stocks include living and standing dead vegetation, woody debris and litter, organic matter in the soil, and harvested stocks such as wood for wood products and fuel.
Carbon stock change or Carbon sequestration	The annual incremental change in carbon stocks.
C_{emis}	CO_2 and other greenhouse gases from project tree-care-related emissions, for example, due to vehicular or equipment use.
C_{proj}	Project carbon, i.e. carbon stored annually in project trees, reported as CO_2.
Direct emissions	Greenhouse gas emissions from sources that are owned or controlled by the reporting entity, e.g. diesel or gasoline use for tree maintenance on city trees by the municipal arborists.
Dry weight (DW) biomass	The weight of aboveground tree biomass when dried to 0% moisture content. Also known as oven-dry and bone-dry biomass. Convert from green biomass to dry weight biomass by multiplying by 0.56 for hardwoods or 0.48 for softwoods.

Entity	The municipality, educational campus, or utility that owns, controls, or manages urban trees, within which project trees are planted.
Freshweight or green biomass	The weight of aboveground tree biomass when fresh (or green), which includes the moisture present at the time the tree was cut. The moisture content of green timber varies greatly among different species. We assume that the moisture content of freshweight biomass is 30%.
Global warming potential (GWP)	Factors used to convert emissions from GHGs other than carbon dioxide to their equivalent carbon dioxide emissions.
Greenhouse gases (GHG)	Any of the gases whose absorption of solar radiation is responsible for the greenhouse effect. Greenhouse gases covered by California's Global Warming Solutions Act (AB 32) are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride.
Indirect emissions	GHG emissions that are a consequence of the reporting company's operations but occur at sources owned or controlled by another company (Source: WRI).
Inherent uncertainty	The scientific uncertainty associated with calculating carbon stocks and greenhouse gas emissions.
Leakage	According to the International Panel on Climate Change: "the unanticipated decrease or increase in greenhouse gas benefits outside of the project's accounting boundary as a result of project activities."
Net tree gain (NTG)	Number of trees planted minus the number removed annually. NTG can be measured at the entity or project level.
Performance standard	Use a common reference for "performance" (GHG emissions or other specific actions) to assess GHG project performance. Performance is based on an analysis of a relevant sector across a range of geographic regions. Performance standards can be used to assess additionality whereby a pre-determined threshold represents performance that is better than business as usual and GHG projects must exceed the threshold.
Performance threshold	A level of emissions performance (measured in absolute emissions rates, or based on market penetration for a given technology, or implementation of a technology standard or management practice) that is better than the average emissions performance for delivery of the same services or outputs.
Project activity	The carbon storage, emission reductions and emissions due to a GHG tree project.
Project developer	The person, company, or organization developing a GHG project.
Project tree site	A tree site that is planted and maintained in tree canopy cover as a result of project activity.

Reporting uncertainty	The level of uncertainty associated with an entity's chosen method of sampling and/or inventorying carbon stock and calculation methodologies. Contrast with inherent uncertainty.
Reporting year	The year for which an entity is reporting its project activity.
Sequestration	The process by which trees remove carbon dioxide from the atmosphere and transform it into biomass.
Tree maintenance plan (TMP)	Describes annual tree maintenance levels of service and associated expenditures.
Tree residue	Aboveground biomass from urban trees (as distinguished from construction debris) that can be salvaged for reuse, such as mulch, wood products, or fuel for biomass power plant.
Tree resource	All trees planted and maintained by an entity.
Verification	The process by which Reserve-accredited third-party verification firms independently review records, data, equipment, and activities to ensure compliance with the eligibility requirements and calculation methodologies laid out by the Reserve's project protocols. Verifiers determine the number of GHG emission reductions attributable to the project.

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Appendix A Urban Forests and Climate Change

Atmospheric carbon dioxide (CO_2) reductions due to trees result from a number of processes: sequestering carbon in live trees, maintaining sequestered CO_2 in removed trees by storing it in wood products, reducing GHG emissions by conserving energy used for space heating and cooling, or displacing GHG emissions by using urban tree residue as bioenergy fuel. At the same time, GHGs released through tree care and decomposition must be accounted for. This appendix provides background information and an in-depth discussion of some of the scientific principles underlying the role of trees and urban forests in GHG emission reductions and the fight against climate change. Recommendations for maximizing GHG benefits through trees are included.

A.1 Carbon Sequestration and Storage in Trees

Carbon sequestration in trees refers to the process by which CO_2 is removed from the atmosphere, transformed into above- and belowground biomass and stored as carbon (C). During photosynthesis, atmospheric CO_2 enters the leaf through surface pores, combines with water, and is converted into cellulose, sugars, and other materials in a chemical reaction catalyzed by sunlight. Most of these materials become fixed as wood, although some are respired back as CO_2 or used to make leaves that are eventually shed by the tree (Larcher 1980).

Data on radial trunk growth are used to calculate annual sequestration for common tree species (Jo and McPherson 1995; Nowak 1994; Peper et al. 2001a, b). Because urban trees partition carbon differently than forest trees, biomass equations developed from measurements of open-grown city trees should be used whenever possible. Sequestration can range from 16 kg/year (35 lb/year) for small, slow-growing trees with 8 to 15 cm diameter at breast height (dbh) (3 to 6 inch dbh) to 270 kg/year (600 lb) for larger trees growing at their maximum rate.

A.2 Energy Conservation and Reduced Emissions

Impacts on space cooling and heating. Tree shade reduces summer air conditioning demand, but can increase heating energy use by intercepting winter sunshine (Heisler 1986; Simpson and McPherson 1998). Lowered air temperatures and wind speeds from increased tree cover decrease both cooling and heating demand. Energy-saving benefits from trees around typical residences have been measured in the field (Parker 1983; Meier 1990/91) and estimated from computer simulations. Simulations for three cities (Sacramento, Phoenix, and Lake Charles) found that three mature trees around energy-efficient homes cut annual air conditioning demand by 25 to 43% and peak cooling demand by 12 to 23% (Huang et al. 1987). On a per-tree basis, energy simulations from 12 U.S. cities found that annual energy savings for cooling from a well-placed 25 ft tall deciduous tree ranged from 100 to 400 kWh (10 to 15%), and peak demand savings ranged from 0.3 to 0.6 kW (8 to 10%) (**Figure A.1**) (McPherson and Rowntree 1993).

Heisler (1986, 1990) estimated that windbreaks can reduce a typical home's demand for space heating by 5 to 15%. For single trees, simulation studies suggest that energy savings from heating due to wind shielding range from 1 to 3% (0.15 to 5.5 MBtu) for a typical energy-efficient residence.

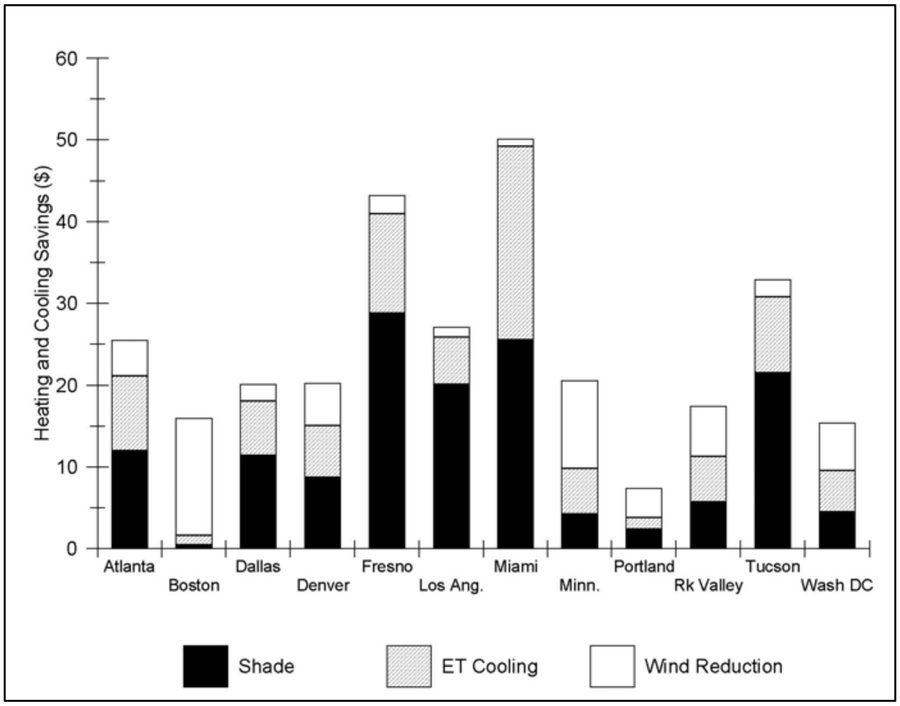


Figure A.1. Simulated total annual heating and cooling savings due to shade from one 7.6 m tall tree, and evapotranspiration (ET) cooling and wind-reduction effects assumed to be associated with a 5% increase in local tree cover (McPherson and Rowntree 1993).

Impacts of building characteristics. The energy use characteristics for space heating and cooling of different types of residential buildings (vintages) influence GHG reductions at power plants from tree planting. Important factors include the building's thermal integrity, its heating, ventilation, and air conditioning equipment, and occupant behavior. Simulated annual air conditioning savings (kWh) for tree plantings near heavily insulated buildings were 35 to 55% of the savings for the same uninsulated buildings (Simpson and McPherson 1996). Also, energy savings associated with ET cooling and wind shielding from vegetation are relatively more important than shading benefits when heat transfer is dominated by infiltration and conduction, as in poorly insulated buildings. However, shading benefits are relatively greater than ET cooling savings for energy-efficient construction because of the increased importance of solar heat gain through windows in these structures.

Impacts of climate and fuel mix. Regional variations in climate and the mix of fuels that produce energy to heat and cool buildings influence potential GHG emission reductions. For example, reduced emissions are likely to be smaller in temperate, coastally influenced climates where energy consumed to heat and cool buildings is relatively small compared to inland locations. Potential GHG reductions are greatest where space cooling loads are the greatest. This is because GHG emissions associated with electrically powered air conditioning are greater than those associated with heating fuels used in California, such as natural gas.

Electricity from a coal fired power plant emits about twice as much CO_2 per unit of energy produced than do fuels such as natural gas. Natural gas gets more of its energy from the combustion of hydrogen rather than carbon, and thus has lower CO_2 emissions than coal. Therefore, large savings of natural gas from reduced heating due to trees in cold-climate cities frequently translate into relatively small CO_2 reductions compared to electricity savings for cooling. In summary, GHG emission reduction benefits from urban forestry are likely to be greatest in regions with large numbers of air-conditioned buildings and long cooling seasons. Also, emission reductions can be substantial where coal is the primary fuel for electric power generation.

A.3 Carbon Dioxide Release

Once trees die or are cut down, they begin to decompose and return the stored C to the atmosphere. The rate of decomposition differs greatly based on the fate of the wood.

A national survey of urban tree residue reported that 67% of the aboveground biomass was chipped, 28% remained unchipped logs, and 5% was classified as other (e.g. fall leaf collection, clippings, whole stumps) (NEOS 1994). Commercial tree care firms and garden/landscapers produced 74% of the total urban tree residue stream, while municipalities produced 19%. Most material was given away (42%), landfilled (17%), sold (12%: 5% mulch, 3% firewood, 2% boiler fuel, other 2%), or left on site (11%). In 1992 only 6% was sent to recycling and 3% burned for energy.

Wood that is chipped and applied as mulch decomposes relatively quickly. For instance, the decomposition rate of landscape mulch in Southern California is about 2 to 4 cm a year (Larson 1997). A study of red pine needle litter (*Pinus resinosa*), a highly lignified material not unlike wood chips, reported that after approximately 4 years, 80% of the original mass was gone (Melillo et al. 1989). Application of fertilizers and irrigation hastens decomposition. Wood salvaged for use in wood products survives 50 years on the average, before gradually decomposing (Norse 1990). Biomass used to produce energy is assumed to be converted immediately to CO_2, but offers GHG benefits when it replaces other fossil fuels.

A.3.1 Decomposition

Urban trees are usually removed soon after they die because of the risk they pose. Boles and branches are frequently recycled as landscape mulch, sold as firewood, or salvaged for wood products. Roots account for about 18 to 24% of total carbon stored in a mature forest tree. The fine roots decompose more quickly than coarse roots. Studies on decomposition indicate that 37 to 56% of the carbon in tree roots is released during the first three years (Scheu and Schauermann 1994). In the UFP, it is conservatively assumed that all of the carbon stored in the root system of trees is instantaneously released to the atmosphere as CO_2 after the tree is removed.

Stumps are often burned or disposed of in landfills. Burning of tree wood results in nearly complete release of stored CO_2. Decomposition of urban tree residue that is disposed of in landfills can take decades. The amount of CO_2 released through decomposition of wood pruned from trees depends on pruning frequency and intensity.

A study of residential green space in Chicago found that about 15% of the CO_2 sequestered each year was eventually released back to the atmosphere through decomposition of woody biomass pruned from trees and shrubs (Jo and McPherson 1995). By selecting tree species that are well adapted to their site in terms of size and growth the need for pruning can be minimized.

Wood Products. In California, cities like Sacramento and Lompoc are recycling municipal trees to create plaques, fences, benches, tables and other furniture. Recycling urban trees into wood products can turn a cost burden into an income-generating opportunity while prolonging the GHG benefits. Tipping fees for disposal of material can be reduced, as well as time and labor costs involved in processing removed trees into low-value products such as chips, mulch, and firewood. Key steps to developing a successful recycling strategy for removed trees include (Bratkovich, 2001; Cesa et al. 2003):

- Identifying existing sawmills in your area or obtaining a portable sawmill;
- Learning what their sawlog requirements are and whether your tree logs fit these requirements. Trees that are at least 30 cm dbh (12 inches) and have a log at least 2 m (6 ft) in length have saw log potential. Normally, the most valuable part of the tree is the 2 to 4 m closest to the ground. Local markets determine desirability of different tree species;
- Locating and removing metal and other foreign material in logs. Embedded metal can damage blades and equipment, but can be detected by most metal detectors; and
- Storing sawlogs until a salable quantity is accumulated.

CalFire supports utilization of removed municipal trees by loaning portable mills to communities, sponsoring workshops, and supporting the Urban Wood Web site (http://www.ufei.org/urbanwood/index.html). Tools (MacFarlane 2007; Pillsbury and Thompson 1995) and technologies such as the computer program CUFIM help municipal foresters calculate the volume of merchantable material in tree removals (Pillsbury and Gill 2003).

Recycling removed trees as wood products delays the release of CO_2, but eventually these products will completely decay.

Bioenergy. Substituting urban tree biomass for fossil fuels as feedstock for biopower plants eliminates GHGs that would have been emitted by combusting fossil fuels. The most common way to convert tree biomass to energy is to burn it to produce heat that powers turbines. Two-thirds of California's installed biomass power capacity consists of solid-fueled steam boilers with net efficiencies of 15 to 27% (California Biomass Collaborative 2006). Integrated gasification combined cycle systems are 40 to 100% more efficient, but just beginning to become operational in the U.S. For this protocol, a biopower plant's heat rate is used to calculate GHG emissions displaced by tree biomass feedstocks. The heat rate expresses the efficiency of conversion from wood fuel to electricity. The local utility's GHG emission factors also influence bioenergy benefits. Utilities with high-emitting fuel mixes will displace more GHG emissions using urban tree biomass than will utilities with lower-emitting fuel mixes.

The cost effectiveness of utilizing removed city trees as a bioenergy feedstock has not been well-researched. Costs are associated with initial processing at the removal site, transporting to a transfer station, processing facility, or bioenergy facility, storing in open piles, and handling, usually through a combination of automatic conveyors and driver-operated front-end loaders. The economic feasibility of this strategy is feedstock, product, and site dependent (California Biomass Collaborative 2005). Where collection and other feedstock acquisition costs are low or offset by tipping fees, longer transport distances to more centralized power generation facilities are economically feasible.

Research is underway to develop more efficient processes for converting wood into fuels such as ethanol, bio-oil, and syngas (Zerbe 2006). However, it will be years before these methods are perfected and scaled-up for widespread commercial application.

A.3.2 Tree care activities

The combustion of gasoline and diesel fuels by vehicle fleets, and by equipment such as chainsaws, chippers, stump removers, and leaf blowers is a GHG emission source that has not been fully quantified. The Sacramento Tree Services Division's vehicle fleet and fossil fuel powered equipment released 1,720 t CO_2 in 1996 or, on a per tree basis, 0.51 kg/cm dbh (McPherson 1998). This amount was 3% of the total CO_2 sequestered and reduced due to energy conservation annually by Sacramento's urban forest. A survey of 13 municipal forestry departments found average annual tree care-related release to be 0.14 kg CO_2 /cm dbh per tree (McPherson and Simpson 1999). Typically, CO_2 released due to tree planting, maintenance, and other program-related activities is about 2 to 5% of annual CO_2 reductions obtained through sequestration and reduced power plant emissions.

Many nonprofit tree programs are relatively small and, therefore, the amount of CO_2 released through office space conditioning and motor vehicle use is minor. However, if the program plants thousands of trees each year, a substantial amount of CO_2 can be released by vehicles. A survey of 12 nonprofit tree programs estimated all present and future program-related CO_2 release on a per-tree planted basis as 2.62 kg CO_2 per tree planted on average (McPherson and Simpson 1999). This amount does not include CO_2 released at nurseries during tree production. A survey of five nurseries found an average of 0.69 kg CO_2 released per tree over the course of the production cycle (McPherson and Simpson 1999).

A full and complete accounting of GHG emissions associated with tree care activities is necessary when assessing the GHG benefit of a tree planting project (Nowak et al. 2002). Therefore, these emissions must be inventoried and reported in the Urban Forest Protocol.

A.4 Carbon Dioxide Reduction through Urban Tree Planting

A.4.1 Within California

Using 1990 aerial photography, McPherson and Simpson (2003) found 177.3 million energy-conserving trees in California communities and 241.6 million empty planting sites. Planting 50 million trees to shade east and west walls of residential buildings was projected to reduce electricity consumption by 46,981 GWh (1.1%) and peak demand by 39,974 MW (4.5%) over the 15 year planning period. This reduced energy use would result in additional GHG benefits from reduced power plant emissions. Based on the average annual projected reduction in air conditioning energy use of 6,408 GWh for mature trees and typical emission coefficients for electric power production in California

(EIA 2002), 50 million new trees would reduce annual power plant emissions by approximately 1.8 Mt (million metric tons) in carbon dioxide equivalents. In a subsequent analysis, we assumed an average annual CO_2 sequestration rate of 90 kg (200 lb) per tree, and found that permanent planting of 50 million tree sites would sequester approximately 68 Mt of CO_2 over 15 years, or 4.5 Mt annually.

In California, the total GHG emissions level in 1990 was 427 Mt and it is expected to increase to 600 Mt in 2020 (CARB 2007). An estimated emissions reduction of 173 Mt annually will be required to meet the statewide goal of reducing GHG emissions to the 1990 level. The large-scale planting program described above would sequester and reduce statewide CO_2 equivalent emissions by 6.3 Mt annually, about 3.6% of the total targeted reduction.

A.4.2 Across the United States

Nowak and Crane (2002) calculated that annual gross carbon sequestration by urban trees in the U.S. is 83.6 Mt CO_2 year, equivalent to total emissions over a 5-day period. Sampson et al. (1992) estimated that planting 225 million trees along streets and on private land in America's 50.3 million acres of "urban and built-up area" would save 103 Mt of CO_2 per year. This total includes storage in soil. Trexler (1991) estimated a potential reduction of 55 Mt of CO_2 annually if all urban forestry planting opportunities were exploited, but concluded a more realistic savings to be 11 to 18 Mt of CO_2 per year.

Total U.S. CO_2 emissions were estimated at 5,900 Mt for 2006 (EIA 2007). Therefore, annual CO_2 reductions achieved through tree planting programs described above could offset about 0.2 to 2% of annual emissions. This potential savings is modest, especially when compared to the 3,000 Mt per year (50% of current U.S. carbon emissions) that an extensive tree planting and forest management program on rural lands is estimated to be able to sequester (Moulton and Richards 1990). The average cost of achieving a 10% CO_2 reduction (476 Mt annually) through rural forest management is about $1 to $3 per ton depending on whether the annual rental value of the land is included in the calculation. This amount is substantially less than the average cost of sequestering CO_2 through urban forestry once realistic assumptions regarding planting and stewardship costs and tree survival are factored into calculations (McHale et al. 2007). Although urban forestry-based carbon offset projects may not be as cost-effective as rural forestry projects, they can provide many social, economic, environmental, political, and public relations benefits.

A.5 Maximizing GHG Benefits

A.5.1 Maximizing carbon sequestration and storage

Sequestration depends on tree growth and mortality, which in turn depends on species composition, age structure, and health of the forest. Newly planted trees accumulate C rapidly for several decades, and then the annual increase in sequestered C declines (McPherson and Simpson 1999). Old trees can release as much C from decay as they sequester from new growth; at the same time, however, they serve as valuable carbon sinks and should be protected lest their entire stored C be released into the atmosphere. When trees are stressed, as during hot, dry weather, they can lose their normal ability to absorb CO_2. Trees close their pores as a defense mechanism to avoid excess water loss. Hence, healthy, vigorous, growing trees will absorb more CO_2 than will trees that are diseased or otherwise stressed.

Although rapidly growing trees sequester CO_2 more quickly initially than slow growing trees, this advantage can be lost if the rapidly growing trees die at younger ages. **Figure A.2** illustrates the difference between CO_2 sequestration by a rapid growing, short-lived tree, the crapemyrtle (*Lagerstroemia indica*), and a slower growing, longer lived tree, the hackberry (*Celtis occidentalis*). The crapemyrtle is estimated to sequester about 148 kg (326 lb) over 30 years, while the hackberry sequesters 3,487 kg (7,687 lb) during 60 years.

Survival of urban trees is another important variable influencing long-term carbon storage. Mortality rates for street and residential yard trees are on the order of 10 to 30% over the first 5 years of establishment, and 0.5 to 3% each year thereafter (Miller and Miller 1991; McPherson 1993; Bond 2006). One key to maximizing CO_2 sequestration is to select tree species that are well suited to the site where they will be planted. Trees that are not well adapted will grow slowly, show symptoms of stress, or die at an early age.

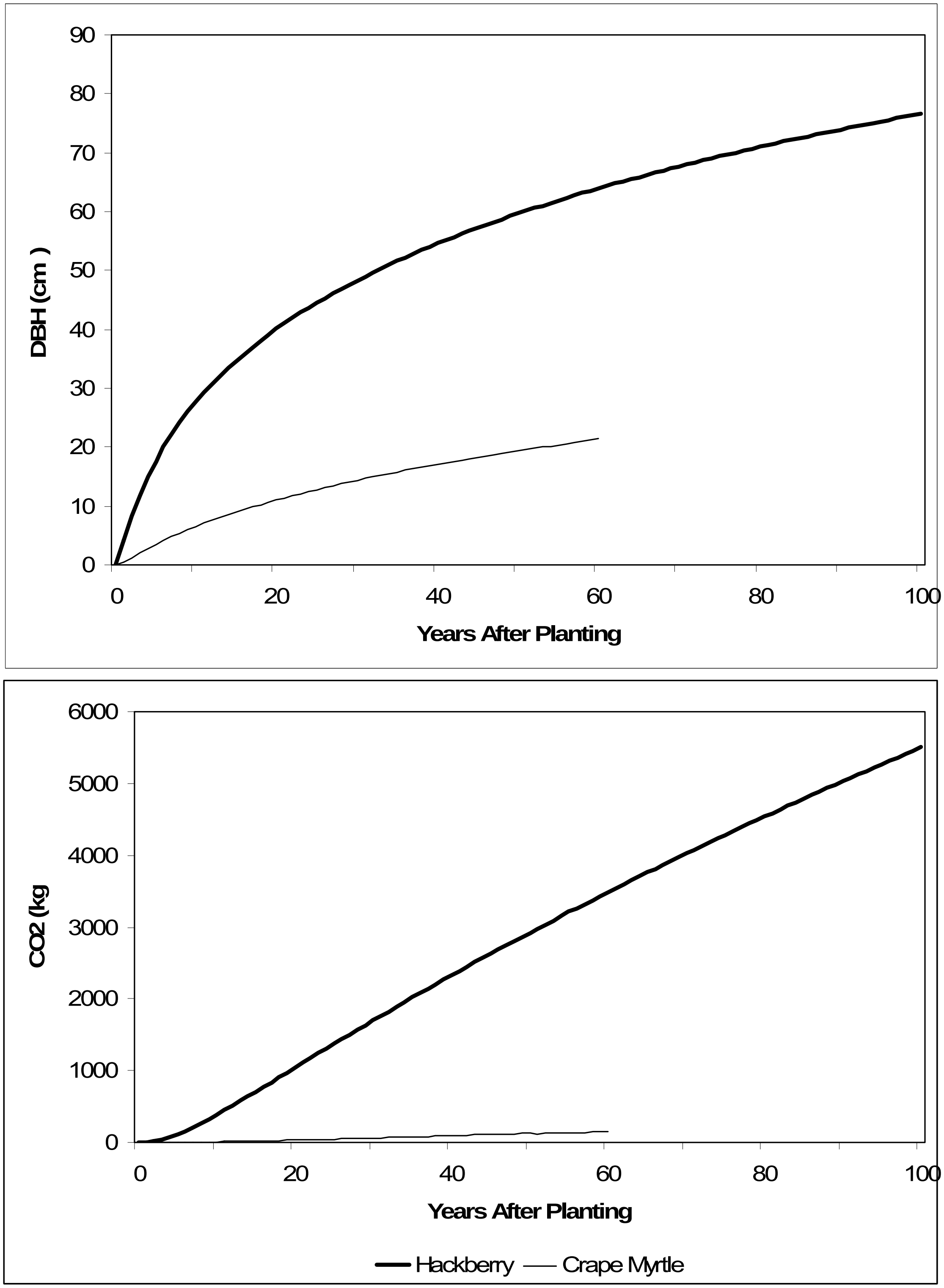


Figure A.2. Growth rate (represented above by dbh over time), tree size, and life span influence CO_2 sequestration. This example from Modesto, California shows that by the end of its life the crape myrtle sequestered 148 kg of CO_2 compared to 3,487 kg for the hackberry at 60 years and 5,504 kg at 100 years. Large trees generally produce greater benefits than small trees.

Design and management guidelines that can increase CO_2 storage include the following:

- Plant more trees where feasible and immediately replace dead trees to compensate for CO_2 lost through tree and stump removal.
- Provide trees with as optimal a growing environment as possible, with plenty of room to grow both above- and belowground.
- Create a diverse assemblage of habitats, with trees of different ages and species, to promote a continuous canopy cover over time.
- Group species with similar landscape maintenance requirements together and consider how irrigation, pruning, fertilization, and weed, pest, and disease control can be minimized.
- Reduce CO_2 associated with landscape management by using push mowers (not gas or electric), hand saws (not chain saws), pruners (not gas/electric shears), rakes (not leaf blowers), and employ landscape professionals who don't have to travel far to your site.
- Provide ample space belowground for tree roots to grow so that they can maximize CO_2 sequestration and tree longevity.

When trees die or are removed, salvage as much wood as possible for use as feedstock for biopower plants or furniture and other long-lasting wood products to delay decomposition.

A.5.2 Maximizing energy savings

Planting trees for shade. The right tree in the right place can save energy and thereby reduce GHG emissions. In midsummer, the sun shines on the east side of a building in the morning, passes over the roof near midday, and then shines on the west side in the afternoon (**Figure A.3**). Electricity use is highest during the afternoon when temperatures are warmest and incoming sunshine is greatest. Therefore, the west side of a building is the most important side to shade (Sand 1993).

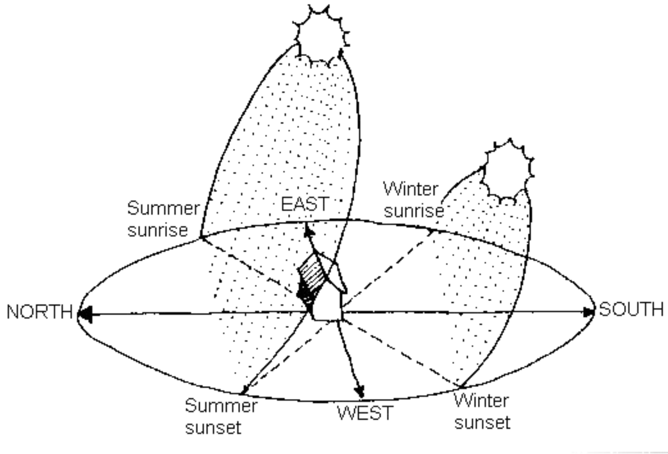


Figure A.3. Paths of the sun on winter and summer solstices (Sand 1991). Summer heat gain is primarily through east- and west-facing windows and walls. The roof receives most irradiance, but insulated attics reduce heat gain to living spaces. The winter sun, at a lower angle, strikes the south-facing surfaces.

Depending on building orientation and window placement, sun shining through windows can heat a home quickly during the morning hours. The east side is the second most important side to shade when considering the net impact of tree shade on energy savings (**Figure A.4**). Deciduous trees on the east side provide summer shade and more winter solar heat gain than evergreens.

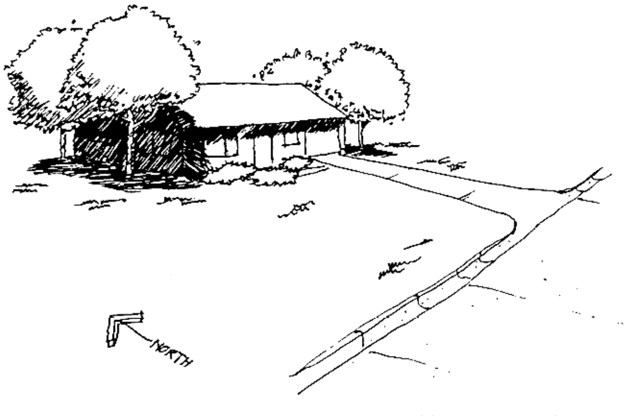


Figure A.4. Locate trees to shade west and east windows (Sand 1993).

Trees located to shade south walls can block winter sunshine and increase heating costs because during winter the sun is lower in the sky and shines on the south side of homes (**Figure A.5**). The warmth the sun provides is an asset, so do not plant evergreen trees that will block southern exposures and solar collectors. Use solar-friendly trees to the south because the bare branches of these deciduous trees allow most sunlight to strike the building (some solar-unfriendly deciduous trees can reduce sunlight striking the south side of buildings by 50% even without leaves) (Ames 1987). Examples of solar-friendly trees include most species of maples, ash, hackberry, and honey locust. Solar-unfriendly trees include most oaks and elms, sycamore, basswood, river birch, and horse chestnut (McPherson et al. 1994).

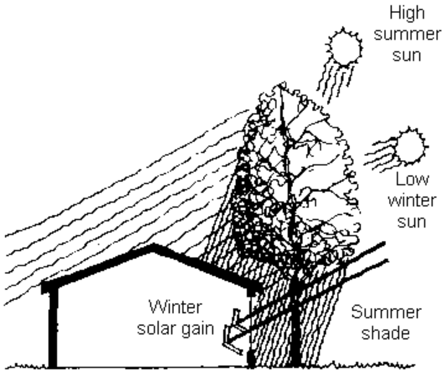


Figure A.5. Select solar-friendly trees for southern exposures and locate them close enough to provide winter solar access and summer shade (Sand 1991).

To maximize summer shade and minimize winter shade, locate shade trees about 10 to 20 ft south of the home. As trees grow taller, prune lower branches to allow more sun to reach the building if this will not weaken the tree's structure (**Figure A.6**).

Figure A.6. Trees south of a home before and after pruning. Lower branches are pruned up to increase heat gain from winter sun (Sand 1993).

Although the closer a tree is to a home the more shade it provides, roots of trees that are too close can damage the foundation. Branches that impinge on the building can make it difficult to maintain exterior walls and windows. Keep trees 10 ft or further from the home depending on mature crown spread, to avoid these conflicts. Trees within 30 to 50 ft of the home most effectively shade windows and walls.

Plant only small growing trees under overhead power lines and avoid planting directly above underground water and sewer lines if possible. Contact your local utility location service before planting to determine where underground lines are located and which tree species should not be planted below power lines.

Planting windbreaks for heating savings. A tree's size and crown density can make it ideal for blocking wind, thereby reducing the impacts of cold winter weather. Locate rows of trees perpendicular to the prevailing wind (**Figure A.7**), usually the north and west side of homes.

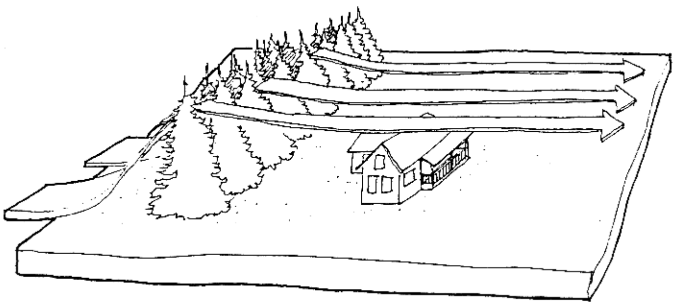


Figure A.7. Evergreens protect a building from dust and cold by reducing wind speeds (Sand 1993).

Design the windbreak row to be longer than the building being sheltered because wind speed increases at the edge of the windbreak. Ideally, the windbreak should be planted upwind about 25 to 50 ft from the building and should consist of dense evergreens that will grow to twice the height of the building they shelter (Heisler 1986; Sand 1991). Avoid planting windbreaks that will block sunlight to south and east walls (**Figure A.8**). Trees should be spaced close enough to form a dense screen, but not so close that they will block sunlight to each other, causing lower branches to self-prune. Most conifers can be spaced about 6 ft on center. If there is room for two or more rows, then space rows 10 to 12 ft apart.

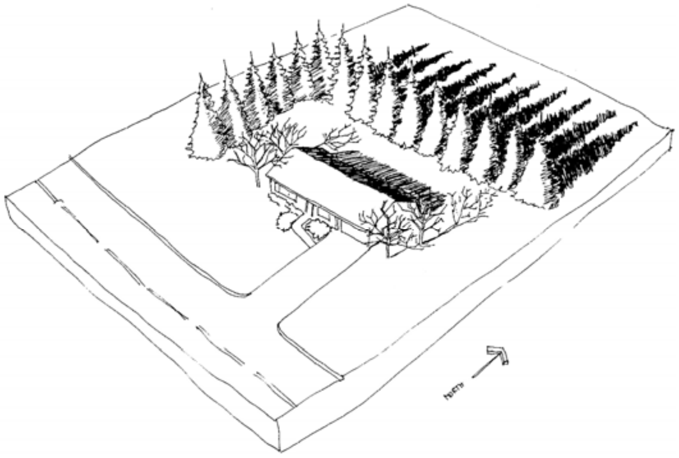


Figure A.8. Midwinter shadows from a well-located windbreak and shade trees do not block solar radiation on the south-facing wall (Sand 1993).

Evergreens are preferred over deciduous trees for windbreaks because they provide better wind protection. The ideal windbreak tree is fast growing, visually dense, has strong branch attachments, and has stiff branches that do not self-prune. In settings where vegetation is not a fire hazard, evergreens planted close to the home create airspaces that reduce air infiltration and heat loss. Allow shrubs to form thick hedges, especially along north, west, and east walls.

Selecting trees to maximize energy benefits. The ideal shade tree has a fairly dense, round crown with limbs broad enough to partially shade the roof. Given the same placement, a large tree will provide more shade than a small tree. Deciduous trees allow sun to shine through leafless branches in winter. Plant small trees where nearby buildings or power lines limit aboveground space. Columnar trees are appropriate in narrow side yards. Because the best location for shade trees is relatively close to the west and east sides of buildings, the most suitable trees will be strong and capable of resisting storm damage, disease, and pests (Sand 1994). Examples of trees not to select for placement near buildings include cottonwoods and silver maple because of their invasive roots, weak wood, and large size, and ginkgos because of their sparse shade and slow growth.

When selecting trees, match the tree's water requirements with those of surrounding plants. For instance, select low water-use species for planting in areas that receive little irrigation. Also, match the tree's maintenance requirements with the amount of care and the type of use different areas in the landscape receive. Check with your local landscape professional before selecting trees to make sure that they are well suited to the site's soil and climatic conditions.

Use the following practices to plant and manage trees strategically to maximize energy conservation benefits:

- Increase community-wide tree canopy, and target shade to streets, parking lots, and other paved surfaces, as well as air-conditioned buildings;
- Shade west- and east-facing windows and walls;
- Avoid planting trees to the south of buildings;
- Select solar-friendly trees opposite east- and south-facing walls;
- Shade air conditioners, but don't obstruct air flow;
- Avoid planting trees too close to utilities and buildings; and
- Create multi-row, evergreen windbreaks where space permits, that are longer than the building.

Appendix B Urban Forest Inventories and Sampling

The Urban Forest Protocol requires collecting information about trees over time. This can be accomplished through field surveys, remote sensing, or a combination of these two approaches. In many cases it may not be practical to perform a complete inventory of every tree in the overall population. However, it is still possible to obtain reliable information about the overall population by collecting data from a representative subset or sample. Sampling is simply the technique used to choose representative units for study from a larger population (Swiecki and Bernhardt 2001). This appendix provides basic information about field survey and remote-sensing approaches, inventories and sampling, and lists additional resources.

B.1 Data Collection Approaches

B.1.1 Field Surveys

Field or ground surveys can provide high quality data on individual trees if inspectors are well-trained and motivated. Although field surveys can take more time than remote sensing, they can provide more accurate data on a greater number of variables. For example, tree dbh can be directly measured for use in biomass equations, whereas with remote sensing it is inferred from measurement of crown projection area (CPA) or average crown diameter. During a field survey information on the condition and management needs of each tree can be collected. These data may trigger actions that will improve tree growth and survival and are more difficult to determine with remote sensing.

Consultants typically charge $3 to $5 per tree for inventory work. This includes locating the tree using a Global Positioning System (GPS), collecting relevant data, delivery of a database, and reporting findings. Using staff or trained volunteers can reduce costs. One to two days of training is recommended, depending on skill levels. Volunteer crews averaged 6 minutes per tree for data collection and travel between trees across randomly located street segments in Minneapolis (Cozad et al. 2005).

B.1.2 Remote Sensing

Remote sensing can provide size information on trees at less cost than field surveys under certain circumstances. Very high resolution imagery is required to accurately measure crown dimensions, such as 15 to 60 cm (6 to 24 inch) pixel size, because lower resolution imagery will not always accurately detect the changes in tree crown growth between measurements. Also, color-infrared imagery (CIR) provides better accuracy than color or black and white imagery because differences between tree crowns and grass or shrubs are easier to detect. CIR imagery also improves the ability to distinguish between tree crowns that are healthy and stressed (Xiao and McPherson 2005).

For tree planting projects, relatively accurate tree location and species data can be entered into a GIS at the time of planting. Once very high resolution imagery is overlaid in the GIS, measurements of tree CPA can be relatively accurate and inexpensive because tree crowns are quickly detected. CUFR's regression equations that predict CPA with dbh for common street tree species in each of 16 U.S. regions can be used to estimate dbh. In turn, dbh values are used in biomass equations to estimate carbon storage.

Remote sensing costs depend on the costs for imagery and processing. Imagery costs vary widely. Many cities regularly contract to obtain very high resolution imagery for property assessment and planning, in which case there may not be a cost. The U.S.D.A. Aerial Photography Field Office acquires and distributes high resolution imagery on a 7-year cycle at no cost. The imagery is usually natural color and there is a 1-year lag time for processing. Also, the U.S.G.S. office in Sacramento has very high resolution imagery for many cities and counties in California. Although there is no cost for this imagery, it may take a year for processing.

Aerial photographs and QuickBird satellite imagery can provide the high resolution required to confirm the presence of young transplants and periodically measure crown size to detect growth. The cost to obtain custom imagery depends on the size of the study area, image type and resolution, and amount of pre-processing desired. Generally, costs range from \$30 to \$150 per km^2.

Image processing involves georeferencing imagery and GIS, locating trees, delineating tree crowns, measuring tree crowns, and deriving dbh. The cost required for processing is estimated to range from \$0.005 to \$0.05 per tree (\$50-\$500/ km^2) depending on area, tree density, and image quality. A sample of trees should be surveyed in the field to assess the accuracy of the remote-sensing approach and to refine techniques. Data from this type of ground-truthing can be used to calibrate remote-sensing results if remotely sensed CPA values are systematically over- or under-estimating actual measures of CPA.

B.2 Complete Inventory

A complete inventory will always provide the most accurate assessment of the tree population. Typically the only bias introduced is from measurement inaccuracies, but establishing measurement protocols, training data collectors, and performing regular quality control assessments should limit this error.

The primary questions to answer when conducting both complete inventories and sampling are 1) what data are necessary to collect, 2) how should these data be recorded – on paper or electronically, and 3) what margin of error is acceptable for samples? The first two questions are data collection issues and are addressed in this section. The third question is a data analysis issue and will be addressed in the sampling section of this appendix.

From an efficiency and accuracy perspective, the use of PDAs (personal digital assistants) or other electronic devices for field data collection is preferable over recording data on paper forms. Electronic devices currently allow for immediate backup of data to a removable disk. Certainly, data could be incorrectly entered, but that occurs with paper forms as well. However, collecting data on paper opens the possibility of a second data entry error when the data are eventually entered into electronic databases for analysis. In contrast, data on PDAs or disks are transferred and immediately ready for quality control and accuracy checks.

B.2.1 Inventory Systems

There are numerous urban tree inventory systems available to consumers ranging from freeware to software packages requiring fee-for-service support. One of the most comprehensive tree inventory and management software lists available is on the USDA Forest Service Northeastern Area State and Private Forestry website at <http://www.na.fs.fed.us/urban/inforesources/inventory/InventorySoftwareListDetails.pdf>. This list is an addendum to *A Guide to Street Tree Inventory Software* (Olig and Miller 1997) available at <http://www.na.fs.fed.us/spfo/pubs/uf/streettree/toc.htm>. This publication provides pertinent information on choosing an inventory system (**Sidebar B.1**) including evaluation procedures and software comparisons. In addition, the *Best Management Practices Tree Inventories* companion guide to the *American National Standards Institute (ANSI) A300 Standards for Tree Care* series provides information on key components and data collection fields for urban tree inventories.

Sidebar B.1. Considerations in selecting an inventory system. (Olig and Miller 1997)

Choosing an inventory program

It is important to make several considerations before purchasing a tree inventory software program.

These can include:

1. Identify your management goals and the data that you need to collect to satisfy these goals. Extraneous data along with missing data will increase agency costs.

2. If you have a computer system and do not plan on upgrading your system in the near future, then choose a program that will operate with the hardware and software that you are currently using.

3. If you need to buy a computer system or plan on upgrading your current system, the hardware requirements for that system depend on the software programs that will be used on it. Your software determines what you need for hardware.

The consequences of not considering the above are numerous, and may include the following:

- *The purchase of a program that is not satisfactory in meeting management goals.*
- *Over-expenditure on a program with more functionality than what is needed to satisfy management goals.*
- *The purchase of a computer system that does not meet software requirements.*
- *Over-expenditure on a computer system that has more functionality than what the agency needs.*
- *The purchase of a program that will not operate with the existing operating system and/or computer hardware.*
- *An excess of time and money spent during data collection and entry for extraneous data that are not needed to satisfy management goals.*
- *A lack of data that should have been collected and entered into the program in order to satisfy management goals.*

Several questions should be asked before purchasing an inventory software program, including:

- *Does the program integrate well with and work similarly to the other programs used by the agency (such as a word processor, spreadsheet, or scheduler)?*
- *Does the program store data in a common (standard) file format so that they can be used with other applications?*
- *Is the software developer keeping up with advances in computer technology (such as operating systems, hardware, and software standards)?*
- *Are software upgrades reasonably priced, and can your existing data be transferred without difficulty?*
- *Is the software developer reputable?*
- *Is the company/developer going to be around (along with their program) for the long term?*
- *Does the company provide sound and reasonably priced technical support?*

B.2.2 What to Record

For assessing and monitoring carbon stocks and energy emission reductions, any database associated with an inventory system must be capable of producing the reports required for project reporting. **Table B.1** shows an example list of key data fields. It uses i-Tree's STRATUM software as an inventory and reporting tool. More detailed components required for a STRATUM inventory are listed in the STRATUM users guide available at <http://itreetools.org/resource_learning_center/elements/i-Tree_v12_UsersManual_Final.pdf>. The manual also includes information on UFORE plot sampling methods based on the *Forest Inventory and Analysis (FIA) Field Core Methods Handbook* (USDA Forest Service 2007).

Table B.1. An example of common data fields for tree inventorying, here taken from the i-Tree STRATUM program.

Data Field	Description	Purpose
Tree Id	unique tree identifier	tree location
Zone	alphanumeric code/name showing management area or zone where tree is located	area/zone comparisons or sampling areas
Street Segment	numeric code used with STRATUM sampling program	used in sampling to predict population by dbh classes
City Managed	numeric code showing city or private tree ownership	asset value, structure
Species Code	alphanumeric code denoting genus and species	species and tree count,
Land Use	numeric code for landuse types (e.g., single family residential, commercial, park)	may assist in stratified sampling
Loc Site	numeric code for tree site (e.g., front lawn, planting strip, median, cutout)	tree location info, stratified sampling, energy benefits
DBH	numeric code for diameter-at-breast-height	growth, structure, age, carbon storage, annualization, costs
Mtce Recommendation	numeric code for recommended mtce (e.g., young tree, mature tree)	tree health,mortality, pruning needs assessments
Priority Task	numeric code for highest priority task to perform on tree	tree health,mortality, pruning needs assessments
Sidewalk Damage	numeric code describing extent of damage	costs, size and species associated with damage
Wire Conflict	numeric code describing utility line conflicts	costs, size and species associated with conflicts
Condition Wood	numeric code describing wood (structural) health of tree	asset value, structure
Condition Leaves	numeric code describing foliar (functional) health of tree	asset value, structure
OtherOne, Two, Three	numeric data field with up to 10 variables to be described by user	3 fields in STRATUM to be defined by user
Setback	distance between tree and nearest air-conditioned/heated space	energy analysis use/energy conservation projects
Tree Orient	numeric data listing 1 of 8 azimuth orientations of tree in reference to building	energy analysis use/energy conservation projects

Essentially, the data to be collected will depend upon your project needs. To estimate carbon stocks, information on tree species and diameter-at-breast height (DBH) are the minimum requirements. For estimating the energy conservation benefits and associated GHG emission reductions, additional data are required on tree distance and azimuth (orientation) from nearby buildings, as well as building vintage and heating and cooling equipment (**Table B.1**).

B.2.3 Measuring Guide and Allowable Error for Primary Measurements

This section describes the minimum data collection fields and allowable measurement error necessary to report an urban forest GHG tree project.

1. Species – The most common method for identifying species in an inventory is the use of species code – usually a four-letter code taken from first two letters of genus and species names, or four letters plus one number when genus and species letters are duplicated in study. Use species coding lists in i-Tree Manual 2.2 as guide. (Example: *Acer saccharum* = ACSA and *Acer saccharinum* (in same study) would be ACSA1).

2. DBH (cm) – measure the diameter at breast height (1.37m) to nearest 0.1 cm using a dbh tape (available from most forestry suppliers). Where possible for multi-stemmed trees forking below 1.37 m measure above the butt flare and below the point where the stem begins forking. When this is not possible, measure DRC as described below. Saplings (DBH/DRC 2.54 - 12.5 cm) will be measured at 1.37 m unless falling under multi-stemmed/unusual stem categories requiring DRC measurements (per FHM Field Methods Guide [Mangold 1998]).

   <u>Diameter at Root Collar (DRC in cm)</u> – adapted from FHM Field Methods Guide. For species requiring diameter at the root collar, measure the diameter at the ground line or at the stem root collar, whichever is higher. For these trees, treat clumps of stems having a unified crown and common root stock as a single tree; examples include mesquite, juniper, and mountain mahogany. For multi-stemmed trees, compute and record a cumulative DRC (see below); record individual stem diameters and a stem status (live or dead) on a separate form or menu as required.

   Measuring DRC: Before measuring DRC, remove the loose material on the ground (e.g. litter) but not mineral soil. Measure just above any swells present, and in a location so that the diameter measurements are reflective of the volume above the stems (especially when trees are extremely deformed at the base).

   Stems must be at least 1.0 ft in length and 1.0 inch in diameter to qualify for measurement; stems that are missing due to cutting or damage must have previously been at least 1.0 ft in length (estimate by checking diameter of wound and compare with diameter and length of other stems – checking taper).

   Whenever DRC is impossible or extremely difficult to measure with a diameter tape (e.g. due to thorns, extreme number of limbs), stems may be estimated and recorded to the nearest 1.0 inch class.

   Additional instructions for DRC measurements are illustrated in **Figure B.1**.

   Computing and Recording DRC: For all trees requiring DRC, with at least one stem 1.0 inch in diameter or larger at the root collar, DRC is computed as the square root of the sum of the squared stem diameters. For a singlestemmed DRC tree, the computed DRC is equal to the single diameter measured.

Use the following formula to compute DRC:
$\text{DRC = SQRT [SUM (stem diameter}^2\text{)]}$
Round the result to the nearest 0.1 in. For example, a multi-stemmed woodland tree with stems of 12.2, 13.2, 3.8, and 22.1 would be calculated as:
$\text{DRC = SQRT }(12.2^2 + 13.2^2 + 3.8^2 + 22.1^2)$
= SQRT (825.93)
= 28.74
= 28.7

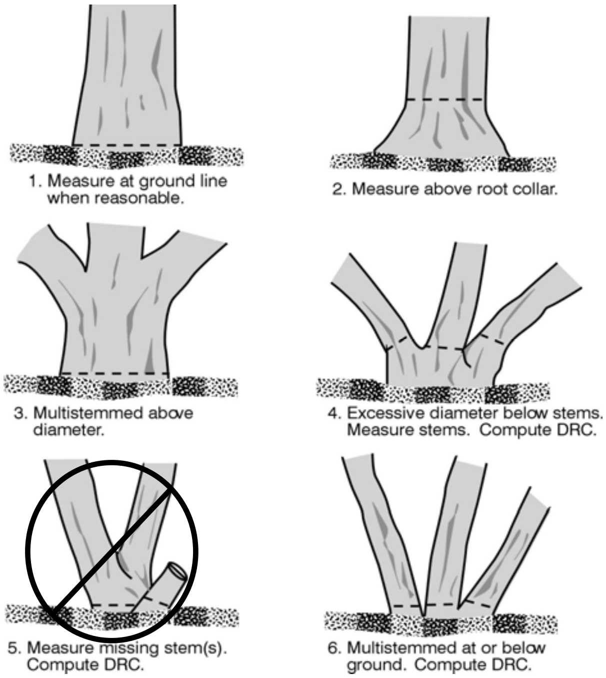


Figure B.1. How to measure DRC in a variety of situations.
Do not measure cut stems as shown in Diagram 5.
Measure only complete stems.

3. Tree height – From ground level to tree top to nearest 0.5 m (omit erratic leader as shown in **Figure B.2**) with range pole, altimeter or clinometer.

Tree height measurement. Measure to white line.

Figure B.2. Tree with erratic leader that should not be included in height measurement.

4. Remote sensing crown projection area (CPA) – the degree of accuracy relies largely on the spatial resolution of the imagery with accuracy improving as source scale increases. Acceptable measurement accuracy should be within 5-10% of actual crown projection. If using low resolution imagery, a subsample using high resolution scale should be digitized and compared to the low resolution CPA estimates. Low resolution estimates should be within 5-10% of high resolution values.

B.3 Sampling from Populations

As previously mentioned, sampling involves measuring only a portion of the trees on the project and using the data to estimate parameters of interest for the overall population. The following information is adapted from Swiecki and Bernhardt (2001) and Wenger's *Forestry Handbook* (1984).

B.3.1 Statistical Bias

The reason for using statistically sound sampling methods is to avoid bias in the estimates of the parameter(s) you are measuring. Although the value of any single estimate (biased or not) is unlikely to equal the true population value, the mean of a large number of unbiased estimates will approximate the true value. In contrast, the mean of a large number of biased estimates will either be higher or lower than the true population value, depending on the direction of the bias. Hence, if you are interested in knowing the actual value of a parameter from the population (e.g. actual tree dbh), you generally want to use an unbiased estimator of that parameter. In some situations, a small bias (e.g. a tendency to slightly over- or underestimate cover) can be tolerated if the bias is small relative to the standard deviation of the estimation errors (perhaps 10% to 15% or less).

Bias in estimates can come from various sources. For instance, if tree shadows are counted as canopy in aerial photo interpretation (misclassification bias), the canopy cover estimate will be biased upward. Many types of bias can be avoided through good sampling design and the careful implementation of appropriate evaluation techniques.

B.3.2 Random Sampling and Random Numbers

Most statistical methods used in environmental areas are based on the assumption of random sampling. This simply means that every unit in the population has an equal chance (or known probability) of being chosen for the sample. Furthermore, the selection of random units should be independent of other units that have been sampled. If you reject a sample unit because you think it is too close to one already chosen, your sample will not be random and independent. A relatively simple and reliable method for randomization is to use random numbers. Most spreadsheet, database, and statistical programs that run on personal computers have functions that generate random numbers. Although these random number generators may not be optimal, they will generally suffice. You can also download random number generators (e.g. <http://www.buffalo.edu/~raulin/random.html> or <http://nhse.npac.syr.edu/roadmap/algorithms/random.html>) or look up random numbers from printed tables.

Several techniques can be used to draw a random sample from a population that consists of individual objects or records (e.g. street addresses or tree numbers). Many spreadsheet programs include tools that can produce a random sample of a specified size from a range of cells. Alternatively, you can assign a unique random number to each unit or record, sort the list based on the random number, and pick the required number of units from the top of the sorted database.

In some cases, it is necessary to take random samples across a geographic area, such as part or all of a city or forested area. In such a situation, random sample points can be assigned by randomly sampling from a coordinate grid that has been established for the area in question. This may either be an existing set of map-based coordinates, such as UTM or State Plane grids, or an arbitrary grid based on units measured on a map or aerial photograph (e.g. distances measured from the bottom and left edge of the map or photo). After you have determined the range of X and Y coordinates within the area to be sampled, X and Y coordinates can be selected randomly to generate random sample points. This is simple random sampling, one of five common random sampling techniques. The other four include systematic sampling, stratified sampling, cluster sampling, and multi-stage sampling. The i-Tree random sampling tool can be used to locate sample plots (http://itreetools.org/applications/sig.shtm).

B.3.3 Systematic Sampling

Systematic sampling means that the sample units are selected at equally spaced intervals over a population. Examples include selecting every tenth tree from a list of trees or selecting sample plots at equally spaced distances over a project area. In carefully planned forest surveys, systematic sampling can yield more precise results than simple random sampling. And systematic sampling is unbiased if the first unit is randomly selected. One advantage to systematic sampling is that is simpler to select one random number and then collect data on every 5th, 10th or 15th (you choose the interval) tree on the list, than to select as many random numbers as the sample size (although these numbers can be generated by any spreadsheet program). It also provides a good spread across a tree population. A disadvantage is that you need a list to start with to be able to know total sample size and calculate a sampling interval. The only advantage of systematic sampling over simple random sampling is the simplicity of needing to choose only one random number.

B.3.4 Stratified Sampling

In many urban forestry applications, it is desirable to have samples distributed throughout the population. For instance, you may want to ensure that trees from each of several different land use zones are included in the sample because you have determined that trees are growing differently in different land use areas due to differences in care and maintenance. In such situations, stratified random sampling will be the most efficient and meaningful method for selecting samples. In this method, the population to be sampled is first divided into meaningful subunits or strata. These may be large subdivisions, planning sectors, maintenance districts, or any other convenient management or planning unit.

If strata are assigned so that each is more or less homogeneous with respect to the characters being measured, fewer samples will be needed to adequately characterize each stratum. For instance, if tree cover is to be assessed in different portions of a city, visual estimates of the tree canopy cover could be used to help demarcate zones where canopy cover is relatively uniform. A sample of street trees might be stratified by tree species, size, and/or age, depending on the purpose of the evaluation. If these trees were classified in a municipal street tree database, stratification might be accomplished relatively simply from existing tree data. However, if such data are lacking, it may be necessary to conduct a preliminary sample to delineate the population before sampling occurs.

Once strata are assigned and delineated, samples are drawn at random from within each stratum. If the number of samples selected from each stratum is not proportional to the size of the stratum, then the averages from each will have to be weighted to obtain an overall population average. Given prior knowledge about the population, stratified sampling is a commonly used probability method that is superior to random sampling because it reduces error.

B.3.5 Sample Size

Optimal sample size will vary somewhat with the characteristics being rated or tallied.

In general:

- Up to a point, the reliability of estimates will increase as sample size increases;
- The more variable the population is with respect to the characteristic(s) being rated, the larger the sample should be;
- A large sample is required to accurately estimate the frequencies of relatively rare events or characteristics; and

- Larger sample sizes are needed to detect relatively small differences between means or proportions; smaller sample sizes may suffice if the differences are relatively large.

The optimum sample size represents a compromise between cost and accuracy, since both generally increase with increasing sample size. You can determine an optimum sample size by identifying the point of diminishing returns beyond which further increases in accuracy are not worth the additional costs of data collection. Optimum sample size will vary with the type of data being collected, so it is not possible to set a single number for all applications.

However, you can use certain statistical formulas to estimate the minimum sample size needed for a specific purpose. A number of statistics web sites include on-line interactive calculators that allow you to estimate required sample sizes. Before you can use these sample size calculators, you will need to know several things about the data you are collecting and how it will be analyzed:

1. *Type of data*. Main types include:
    a. Continuous – variables can take any value, e.g. tree diameters.
    b. Discrete – variables can only have certain discrete values. Types of discrete data include:
        i. Ranks – ordered ratings, e.g. low, moderate, high.
        ii. Counts – e.g. number of trees by species or dbh class.
        iii. Binary – variable has only two outcomes, e.g. present/absent. Binary data is typically expressed as proportions or percents, such as the percent canopy cover determined from dot grid counts (canopy is rated as present or absent for each dot).

2. *Type of analysis*. Continuous data are typically analyzed using linear models, including linear regression and analysis of variance techniques. Discrete data may be analyzed in various ways, including contingency table analysis, logistic regression, and survival analysis. Different formulas are used to estimate sample sizes for various analysis methods.

3. *Expected values*. To estimate sample sizes for analyses of continuous data you will have to specify estimates of expected population means (the Greek letter mu may be used for this term) and standard deviations or variances (the Greek letter sigma symbolizes the population standard deviation; variance is the square of the standard deviation). For proportions, estimates of the expected proportions are needed; margins of error (as percents) may also be needed.

4. *Data structure*. If data are paired or arranged in blocks or other more complex designs, the structure of the statistical model should be specified.

5. *Confidence level*. Also abbreviated as the Greek letter alpha, this is the probability of Type I error, the chance that you will say that a difference is significant when it really is not (i.e. the probability of rejecting the null hypothesis when it is true). This is typically set a low level, often 5% (alpha=0.05), meaning that there would only be a 5% (1 in 20) chance of

deciding that a spurious difference is real (i.e. you have a 95% chance of avoiding Type I error).

6. *Power*. This parameter is the flip side of the confidence level, and is expressed as (1-beta) where beta is the probability of Type II error. Power is the probability of detecting a real difference (i.e. the probability of rejecting the null hypothesis when it is false). If you are interested in detecting real differences, the power of a test should be high, generally at least 80% (0.8) or greater.

B.3.6 Sampling Design and Monitoring Frequency

The frequency of monitoring is related to the rate and magnitude of change in tree growth, removal rates, planting rates and so forth – the smaller the expected change, the greater the potential that frequent monitoring will not detect a significant change. Frequency of monitoring should be determined by the magnitude of expected change – less frequent monitoring is applicable if only small changes are expected (Brown et al. 2004). One area of possible error in estimating carbon stocks is that tree growth rates in a locale may significantly differ from the regional tree growth rates used by the CUFR Tree Carbon Calculator (CTCC; Appendix D). In this case monitoring would need to be conducted more frequently as a basis for adjusting growth rates to local conditions and reducing error.

All sampling designs should incorporate some form of random sampling to quantify the carbon, bioenergy and/or energy conservation resources within established project boundaries using statistically accepted methods for inferring the urban forest biomass based on sample plots. There are multiple ways one can design a sampling plan. Although a few examples are provided here, it is important to remember that the specific sampling method used should be determined after evaluating project size, monitoring frequency and acceptable level of sampling error. We address four basic designs here and provide additional resources in the reference section.

1. *Rolling sample* – A percentage of the complete inventory is sampled annually, with results used to infer biomass or volume for the complete inventory for the annual report or used to update growth data for the project tree population. Example: during year 1 a non-profit tree group plants 3,000 new tree sites along a greenway, with a variety of species mixed throughout the area. Each year, 10% of the tree sites are sampled, until, at the end of 10 years, 100% of the inventory has been sampled. The annual 10% samples are fixed samples proportional to representation. Thus, the complete inventory is divided into 10 samples at the outset of the project. On an annual basis, all the data may be used by updating (growing) the older data. In forest inventories this option has produced tighter confidence intervals than inferring results from the sample to the population. These 10% samples may be based on stratified random sampling with species type and frequency (number of trees planted per species) as the strata, or to reduce data collection costs, trees could be clustered into 10 cohorts based on geographic proximity. Other forms of random sampling, including cluster sampling for obtaining the 10% sample may also be suitable.

2. *Periodic sampling* – All trees are re-inventoried but not annually. A sampling period is determined at the outset. For example, all trees are re-inventoried every 10 years. This approach does not provide interim data for annual monitoring reports that are calculated using the DBH and height tables developed for the region (see Biomass Estimation and Forecasting Tables section below).

3. *Fixed plot sampling* – All trees in a geographical area are never completely inventoried. A set of plots of fixed size and number are established and used to extrapolate volume or biomass on an area basis. Example: the city of San Francisco establishes a new 30-mile long multi-use greenway along a former railroad corridor. They employ the UFORE plot sampling method (see references) and establish thirty 10-m radius permanent plots based on land use stratification. The plots are sampled annually. Biomass or volume for the greenway is extrapolated based on sample plots to area relationship.

4. *Variable plot* – Similar to fixed plot except the area sampled varies to coincide w/ logistical requirements, such as property boundaries where permission to access private property is required. Area of the plot is measured and used to infer to the total area based on plot area to total area ratio.

5. Note that items 1 and 2 can be applied to items 3 and 4; they are potentially at different levels or scales within a sampling design. There are many additional methods for sampling. See the list of recommended references and resource guidelines for developing sampling methodologies and finding statistical support for sampling and extrapolation at the end of this appendix.

B.3.7 Minimum Required Sampling Criteria

All sampling methodologies and measurement standards must be statistically sound and reviewed by verifiers. All sample plots should be permanently benchmarked for auditing and monitoring purposes. Plot centers, street segments, or individual trees (in the case of some forms of rolling samples) should be referenced on maps, preferably from GPS coordinates. The methods utilized shall be documented and made available for certification and public review. The design of your sampling methodology and measurement standards must include the requirements stated in **Table B.2**.

Table B.2. Minimum required sampling criteria.

Carbon Pool	Required Pool?	Name of Requirement	Description of Requirement
Tree Biomass	Yes	Diameter (breast height) Measurements	Stated minimum diameter in methodology not to be greater than 7.6 cm (3 in).
		Measurement Tools	Description of tools used for height, diameter, and plot measurement. For project trees remotely sensed describe methods of measurement, calibration, and field validation.
		Measurement Standards	The methodology shall include a set of standards for height, diameter and crown projection area (for remote sensing) measurements and describe compliance with allowable measurement error.
		Stratification Design	A description of the rules used to stratify the vegetation.
		Plot Layout	A description of the plot layout.
		Allometric Equations used for Estimating Biomass	The methodology shall include a description of the allometric equations used to estimate the whole tree biomass (bole, branches, and roots) from bole diameter or crown projection area measurements.This includes a description of how equations were assigned and implemented. Any diversion from the provided equations will need to be approved by the Registry.
Energy Conservation & Reduced Emissions	No	Diameter (breast height) Measurements	Stated minimum diameter in methodology not to be greater than 7.6 cm (3 in).
		Measurement Tools	Description of tools used for height, diameter, and plot measurement.
		Measurement Standards	The methodology shall include a set of standards for height, diameter, distance and azimuth measurements.
		Tree Eligibility	A description of the rules used to determine eligibility of a tree. Tree needs to be deemed eligible and alive and eligibility may differ from those trees included in the tree biomass pool.
		Climate Zone	Description of rules used to select climate zone.
		Building Data	Description of methods used for building vintage, heating and cooling equipment determination.
		Allometric Equations used for Estimating Tree Size	The methodology shall include a description of the allometric equations used to estimate the whole tree biomass (crown diameter, crown height and bole height from dbh if equations differ from those used by the CCC.

B.3.8 Sampling Error

The Reserve requires all estimates of reported carbon pools, required or not, to have a high level of statistical confidence. Measurement standards are established by the Reserve for the carbon ton estimate in the required pools derived from sampling. Confidence in the estimate of carbon tons from sampling can be measured statistically in terms of the size of the standard error relative to the estimate of the mean. This establishes confidence limits and can be expressed as a percentage of the mean. Larger confidence intervals indicate that there is less confidence in the mean estimate than smaller confidence intervals. For all carbon pools reported to the Reserve, the standard error must be within 20% of the estimate of the mean for the estimate to be accepted. However, estimates are adjusted based on the statistical level of confidence, such that only estimates with a standard error within 5% or less receive no deduction. Most spreadsheet software packages provide users the ability to run descriptive statistics on a set of data, and results include the mean, standard error, standard deviation and confidence level. **Table B.3** below provides an example of summary results for each plot in a measured stratum. Note that standard deviation quantifies the scatter, how much the measured values differ from one another, whereas, standard error quantifies how accurately you know the true mean of the population. Standard error gets smaller as the sample gets larger, but standard deviation does not change predictably since it only quantifies scatter.

Table B.3. Shows summary results for each plot in a stratum. Note that confidence level is less than 10% of the mean as required by the Registry.

Plot #	Carbon Tons per Hectare	Plot #	Carbon Tons per Hectare	Plot #	Carbon Tons per Hectare
1	337	8	367	15	342
2	296	9	260	16	366
3	308	10	260	17	355
4	271	11	322	18	423
5	289	12	323	19	437
6	228	13	439	20	156
7	144	14	309		
Average Carbon Tons per Hectare					312
Standard error (must be <20% of mean)					17.85

B.4 Conclusion

Data collection through complete inventory or sampling represents a means to an end – information used to calculate and report carbon stocks, bioenergy resources, and energy conservation. What sampling methods are used to collect data and how that data are subsequently analyzed will influence predictions of carbon stocks and GHG emission reductions. Remember, it is always best to consult with a statistician when deciding upon a sampling scheme. There is little a statistician can do to help you once you have committed yourself to an inappropriate sampling design.

In collecting necessary information about your project, you must consider the final product – what are your goals in collecting data and what information does that data need to provide for you? There is a series of checklists produced by Jeffers (http://www.sawleystudios.co.uk/jnrj/Statistical.htm) and used by researchers and statisticians world-wide to help them remember all there is to consider regarding data collection and analysis. The website provides individual lists of questions to ask regarding 1) design of experiments, 2) sampling, 3) modeling, 4) plant growth analysis, and 5) multivariate analysis.

B.5 Resources

B.5.1 Inventories, Measurement, and Analyses – General Forest Resources

Avery, T.E., Burkhardt, H.E. (eds.). 1983. Forest Measurements, 3rd Edition. New York: McGraw-Hill. 408 pp.

Brown, J.K. 1974. Handbook for Inventorying Downed and Woody Material. General Technical Report INT-16. Ogden, Utah: USDA Forest Service Intermountain Forest and Range Experiment Station. 24 pp.

Brown, S., Schoch, T. Pearson, Delaney, M. 2004. Methods for Measuring and Monitoring Forestry Carbon Projects in California. Winrock International, for the

California Energy Commission, PIER Energy-related Environmental Research. 500-04-072F.

Jeffers, J.N.R. 2007. Statistical checklists. Accessed via the World Wide Web at http://www.sawleystudios.co.uk/jnrj/Statistical.htm on 6 December 2007.

USDA Forest Service. 2007. Forest inventory and analysis national program. Field guide or Phase 2 measurements. http://fia.fs.fed.us/library/field-guides-methods-proc/.

Wenger, K.F. (ed.) 1984. Forestry Handbook, 2nd Edition. New York: J Wiley & Sons. 1360 pp.

B.5.2 Inventories of Urban Trees

Olig, G.A., Miller, R.W. 1997. A Guide to Street Tree Inventory Software. http://www.na.fs.fed.us/spfo/pubs/uf/streettree/toc.htm. [Note: info not limited to street trees].

Pillsbury, N.H., Gill, S.J. 2003. Community and urban forest inventory and management program (CUFIM). Technical Report No. 11, San Luis Obispo, CA: Urban Forest Ecosystem Institute. 37 pp.

Swiecki, T. J.; Bernhardt, E. A. (2001). Guidelines for Developing and Evaluating Tree Ordinances. http://www.isa-arbor.com/publications/ordinance.aspx.

Tools for Assessing and Managing Community Forests: i-Tree Software Suite v. 2.0 Users Manual http://www.itreetools.org/.

B.5.3 Sampling and Statistics

Cochran, W.G. 1977. Sampling Techniques, 3rd Edition. New York: John Wiley & Sons. 428 pp.

Christopher, H., Schmitt, D. Environmental sampling and monitoring primer: regional sampling methods. http://www.cee.vt.edu/ewr/environmental/teach/smprimer/design/sample.html.

Draper, N.R., Smith, H. 1998. Applied Regression Analysis, Third Edition. New York: John Wiley & Sons. 706 pp.

Snedcor, G.W., Cochran, W.G. 1980. Sample surveys in: Statistical Methods. Ames, Iowa: Iowa State University Press. 507 pp.

B.5.4 Links to Sample-Size Calculators

Some useful web sites with sample-size calculators (Swiecki and Bernhardt 2001) are listed below. Additional sites can be found by following links on some of these pages or by searching on the term "sample size" on various web search engines.

http://www.stat.uiowa.edu/~rlenth/Power/ : **Russ Lenth's Java applets for power and sample size -**This site provides a variety of powerful but easy to use applets

that allow you calculate sample size and interactively see how sample size, power, alpha, and other study design factors are interrelated.
http://home.clara.net/sisa/index.htm : **SISA: Simple Interactive Statistical Analysis -** This site includes a number of statistical analysis applications that can be run interactively online. It includes sample size calculators for both continuous and binary (proportion) data.

http://www.health.ucalgary.ca/~rollin/stats/ssize/ : Four basic and easy to use JavaScript-based calculators for sample size or power.

http://www.answersresearch.com/calculators/sample.htm : One of various basic sample size estimators used for public polling surveys. This provides sample sizes based on the margin of error desired in a survey. Several other survey-related calculators are also provided here.

http://www.mc.vanderbilt.edu/prevmed/psintro.htm : **Power and Sample Size Estimation -** A downloadable application (PS) for calculating sample size and power.

Appendix C Calculating and Predicting Biomass and Carbon

This appendix describes how measured tree size data are used with biomass equations to calculate tree volume and stored carbon. Equations are presented for 26 open-grown urban tree species. To be consistent with biomass equations used in the Forest Protocol, foliar biomass is not included in the formulations. Additional biomass equations have been adapted from the literature on natural and native forest biomass for use in urban settings. We have also used the urban species equations to develop two general equations for broadleaf trees and conifers. These equations are used in the CUFR Tree Carbon Calculator (CTCC, Appendix D). Complete listings of equations are available in **Tables C.1** and **C.2** at the end of this appendix. **Table C.1** lists equations based on measurements of dbh and height or dbh only, derived from data collected on open-grown trees.

C.1 Estimating Biomass and Carbon Using Volumetric Equations

Estimating biomass and carbon using volumetric equations is a two-step process that entails 1) calculating green volume, and 2) converting green volume to dry weight biomass and then carbon (C) and stored carbon dioxide equivalents (CO_2). **Tables C.1** and **C.2** provide examples of volumetric equations and biomass conversion factors for common urban species (Pillsbury et al. 1998; McHale 2008). **Table C.1** equations estimate volume (m^3/tree) from diameter at breast height (dbh in centimeters) and height (in meters) measurements.

1. Use equations for dbh and height (or equations for dbh only if necessary) to calculate volume.

   Example:

   Volume in cubic meters (V) for a 15.6 m tall hackberry (**Celtis occidentalis**) with a 40.4 cm dbh is calculated as:

   $$V = 0.002245 \times (40.4)^{2.118} \times (15.6)^{-0447} = 1.66 \text{ m}^3 \qquad \text{[Eq. 1]}$$

2. Determine freshweight (FW) biomass, dry weight (DW) biomass and carbon stored by applying biomass conversion factors in **Table C.1**, incorporating belowground biomass, and calculating carbon.

   a. Convert from volume to FW biomass by multiplying V by the species-specific density factor.

   For hackberry, FW would be calculated as:

   $$FW = 1.66 \times 801 = 1329.66 \text{ kg} \qquad \text{[Eq. 2]}$$

   b. The equations given here only calculate volume (and hence biomass) for the *aboveground* portion of the tree. Add the biomass stored belowground by multiplying the FW biomass by 1.28. For total FW biomass, including belowground roots calculate:

$$\text{Total FW} = 1329.66 \times 1.28 = 1704.62 \text{ kg} \quad \text{[Eq. 3]}$$

c. Convert FW biomass into DW biomass by multiplying by the constant 0.56 for hardwoods and 0.48 for conifers (Nowak 1994). For our hackberry example:

$$\text{DW} = 1704.62 \times 0.56 = 954.59 \text{ kg} \quad \text{[Eq. 4]}$$

d. Convert DW biomass into kilograms of carbon (C) by multiplying by the constant 0.50:

$$\text{C} = 954.59 \times 0.5 = 477.30 \text{ kg} \quad \text{[Eq. 5]}$$

e. Convert stored carbon into stored carbon dioxide (CO_2) by multiplying by the constant 3.67 as follows:

$$CO_2 = 477.30 \times 3.67 = 1751.69 \text{ kg} \quad \text{[Eq. 6]}$$

f. Stored carbon dioxide is to be reported in metric tons. Therefore, results calculated in kilograms must be multiplied by 0.001 to convert to metric tons.

C.1.1 Estimating Biomass and Carbon Using Forest-Derived Equations

Biomass calculated using equations derived from native or natural forest trees (**Table C.2**) must be adjusted by a factor of 0.80 when applied to open-grown, urban trees (Nowak 1994) because of differences in biomass allocation between the tree populations.

Unlike the equations used above, the forest equations listed produce DW biomass rather than FW biomass. Therefore the step involving the species-specific density factor (step 2a above) does not need to be incorporated. The calculation for CO_2 stored (kg) is:

$$CO_2 = \text{DW} \times 1.28 \times 0.5 \times 3.67 \quad \text{[Eq. 7]}$$

C.1.2 Estimating Tree Biomass for Standing Dead or Dying Trees

Unlike trees in forest settings, dead or dying trees in urban areas are usually removed immediately due to safety concerns in public and private areas. Typically, the only difference between biomass in a live tree and that in a dead tree is the absence of foliage for the latter. Because foliar biomass is not included in these formulations, dead and dying tree biomass should be calculated just as for live tree biomass.

C.1.3 Estimating Carbon in Lying Tree Biomass

As discussed in C.1.2 above, it is assumed in nearly all urban applications that dead/dying trees are removed almost immediately and that lying tree biomass will rarely, if ever exist. It is most likely to exist in natural settings within cities like riparian or nature areas. In that case, sampling, measurement and carbon estimation procedures should follow the forest protocols rather than the urban forest protocols.

C.2 Biomass Forecasting

Biomass forecasting requires estimates of future tree dbh and height growth. The CTCC described in Appendix D uses mean regional tree growth data to forecast the increase in baseline biomass and carbon for up to 100 years. Users may enter tree age, and the CTCC estimates biomass and carbon using tree growth and size equations for age, dbh, and height derived from 20 species of street trees in each of six cities that represent six California climate zones (**Figure C.1**).

For example, if a shopping mall owner wants to estimate the potential carbon stored 20 years after planting 400 green ash saplings around the perimeter of mall parking lots, she decides to use the CTCC and enters 20 years for tree age. The CTCC, based on mean growth equations for each climate zone, estimates dbh and height at year 20 for green ash as 29.9 cm and 13.4 m, respectively. It uses these values with the appropriate volume equation and factors (**Tables C.1** and **C.2**) to predict that the 400 trees will store 485.9 t of carbon in 20 years:

$$\begin{aligned} CO_2 &= (0.000414 \times (29.9)^{1.847} \times \\ &\quad (13.4)^{0.646})(785)(1.28)(0.56)(0.5)(3.67)(400)(0.001) \\ &= 485.9 \text{ t} \qquad [\text{Eq. 8}] \end{aligned}$$

Figure C.1. The 6 regions and the reference cities where tree size data were collected.

C.3 Error in Predicting Future Growth, Carbon and Biomass

The predictive height and dbh equations used by the CTCC for the six regions are based on data collected from a stratified (by dbh) random sample of the predominant trees in a single reference city for each region.

Additionally, all of the volume equations were developed from trees that may differ in size from the trees in your sample or inventory. The dbh ranges for trees sampled to develop the volume and biomass equations are listed where known at the end of the appendix (**Tables C.1** and **C.2**). Applying the equations to trees with dbh outside of this range may increase the error in your predictions.

Your tree growth may differ significantly from tree growth models used by the CTCC. Therefore, it is important to attempt to quantify differences at the beginning of the project and through subsequent monitoring, to assess differences. It is also better to err on the side of underestimating carbon stocks rather than overestimating.

Initial suggestions for evaluating growth include contacting local arborists and other tree experts (e.g. local university extension offices, city tree managers) to evaluate the growth presented here. Obtaining information on “typical” annual growth is important – whether a species normally grows 1 cm per year or 3 cm per year is helpful. Asking arborists for average annual dbh growth when trees are young, adolescent, middle-aged and senescent can allow for further comparison with data produced by the CTCC.

Monitoring more frequently at the start of your project to determine local growth rate differences is also recommended. Ultimately, you may need to develop local growth curves if differences between your tree population and the tables are beyond the 90% confidence level required.

C.4 Reporting Uncertainty vs. Inherent Uncertainty

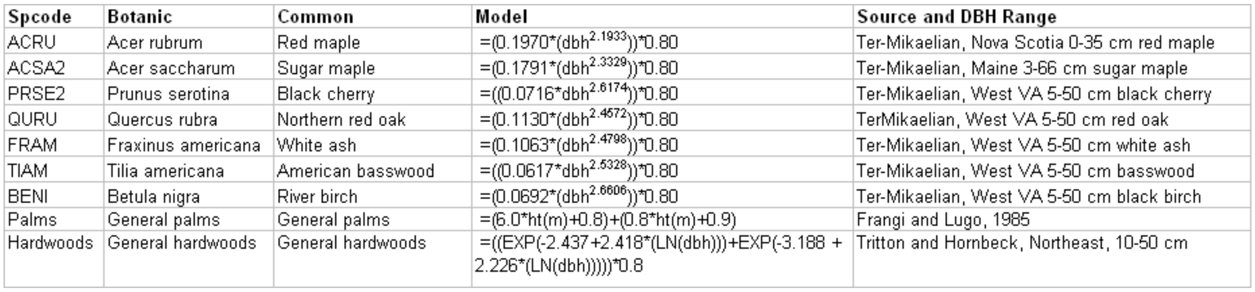
Reporting uncertainty is the level of uncertainty associated with an entity’s chosen C stock sampling and calculation methodologies. Inherent uncertainty refers to the scientific uncertainty associated with calculating C stocks and GHG emissions.

The California Registry is aware that there is an inherent scientific uncertainty in quantifying C stocks of entities. However, determining scientific accuracy is not the focus of California Registry. Instead, California Registry’s verification process is designed to identify and assess reporting uncertainty. Therefore, when assessing if your estimate of the CO_2 stored in your project trees meets California Registry’s minimum quality standard, you should only consider quantification differences that result from reporting uncertainty, not inherent uncertainty. Therefore, it is not necessary to attempt to quantify modeling error for growth and biomass equations accepted by California Registry. Any statistical error associated with these models falls under the category of inherent uncertainty.

Table C.1. Volume equations for 26 urban tree species requiring dbh (cm) only or dbh (cm) and height (m) measurements to calculate volume (McHale 2008; Pillsbury et al. 1998). Factors are listed for converting volume to freshweight (FW), and two FW general biomass equations derived from these species are also listed.

	Species	**DBH Range (cm)**	**Volume (m³)**	**Vol to FW Conversion kg/m3**
	Acacia longifolia	15.0 - 57.2	=0.0283168466 (0.048490 * $(dbh/2.54)^{2.347250}$)	1121
	Acer platanoides	9.7 - 102.1	=0.0019421 * $dbh^{1.785}$	737
	Acer saccharinum	13.2 - 134.9	=0.000363 * $dbh^{2.292}$	721
	Celtis occidentalis	10.9 - 119.4	=0.0014159 * $dbh^{1.928}$	801
	Ceratonia siliqua	15.5 - 71.4	=0.0283168466(0.066256 * $(dbh/2.54)^{2.128861}$)	961
D	Cinnamomum camphora	12.7 - 68.8	=0.0283168466(0.031449 * $(dbh/2.54)^{2.534660}$)	817
B	Cupressus macrocarpa	15.7 - 146.6	=0.0283168466(0.035598 * $(dbh/2.54)^{2.495263}$)	577
H	Eucalyptus globulus	15.5 - 130.0	=0.0283168466(0.055113 * $(dbh/2.54)^{2.436970}$)	1121
	Fraxinus pennsylvanica	14.7 - 122.7	=0.0005885 * $dbh^{2.206}$	785
O	Fraxinus velutina 'Modesto'	14.5 - 84.8	=0.0283168466(0.022227 * $(dbh/2.54)^{2.633462}$)	769
N	Gleditsia triancanthos	9.1 - 98.3	=0.0005055 * $dbh^{2.220}$	977
L	Gymnocladus dioicus	10.2 - 36.8	=0.0004159 * $dbh^{2.059}$	929
Y	Jacaranda mimosifolia	17.3 - 59.7	=0.0283168466(0.036147 * $(dbh/2.54)^{2.486248}$)	609
	Liquidambar styraciflua	14.0 - 54.4	=0.0283168466(0.030684 * $(dbh/2.54)^{2.560469}$)	801
	Magnolia grandiflora	14.5 - 74.2	=0.0283168466(0.022744 * $(dbh/2.54)^{2.622015}$)	945
	Pinus radiata	16.8 - 105.4	=0.0283168466(0.019874 * $(dbh/2.54)^{2.666079}$)	705
	Pistacia chinensis	12.7 - 51.3	=0.0283168466(0.019003 * $(dbh/2.54)^{2.808625}$)	657
	Platanus acerifolia	15.5 - 73.9	=0.0283168466(0.025170 * $(dbh/2.54)^{2.673578}$)	833
	Populus sargentii	6.4 - 136.7	=0.0020891 * $dbh^{1.873}$	753
	Quercus ilex	12.7 - 52.1	=0.0283168466(0.025169 * $(dbh/2.54)^{2.607285}$)	1186
	Quercus macrocarpa	10.9 - 100.1	=0.0002431 * $dbh^{2.415}$	993
	Tilia cordata	11.2 - 64.5	=0.0009359 * $dbh^{2.042}$	673
	Ulmus americana	17.5 - 114.3	=0.0018 * $dbh^{1.869}$	865
	Ulmus parvifolia chinensis	17.3 - 55.9	=0.0283168466(0.028530 * $(dbh/2.54)^{2.639347}$)	865
	Ulmus pumila	15.5 - 131.6	=0.0048879 * $dbh^{1.613}$	865
	Zelkova serrata	14.5 - 86.4	=0.0283168466(0.021472 * $(dbh/2.54)^{2.674757}$)	865
	General Broadleaf	6.4 - 136.7	=0.280285*(dbhcm)^2.310647	Eqtn produces FW
	General Conifer	6.4 - 136.7	=0.05654*(dbhcm)^2.580671	Eqtn produces FW
	Acacia longifolia	15.0 - 57.2	=0.0283168466(0.01406 * $(dbh/2.54)^{2.18649}$ * $(3.28*ht)^{0.46736}$)	1121
	Acer platanoides	9.7 - 102.1	=0.001011 * $dbh^{1.533}$ * $ht^{0.657}$	737
	Acer saccharinum	13.2 - 134.9	=0.000238 * $dbh^{1.998}$ * $ht^{0.596}$	721
D	Celtis occidentalis	10.9 - 119.4	=0.002245 * $dbh^{2.118}$ * $ht^{-0.447}$	801
B	Ceratonia siliqua	15.5 - 71.4	=0.0283168466(0.00857 * $(dbh/2.54)^{1.79584}$ * $(3.28*ht)^{0.92667}$)	961
H	Cinnamomum camphora	12.7 - 68.8	=0.0283168466(0.00982 * $(dbh/2.54)^{2.13480}$ * $(3.28*ht)^{0.63404}$)	817
	Cupressus macrocarpa	15.7 - 146.6	=0.0283168466(0.00576 * $(dbh/2.54)^{2.26035}$ * $(3.28*ht)^{0.63013}$)	577
a	Eucalyptus globulus	15.5 - 130.0	=0.0283168466(0.00309 * $(dbh/2.54)^{2.15182}$ * $(3.28*ht)^{0.83573}$)	1121
n	Fraxinus pennsylvanica	14.7 - 122.7	=0.000414 * $dbh^{1.847}$ * $ht^{0.646}$	785
d	Fraxinus velutina 'Modesto'	14.5 - 84.8	=0.0283168466(0.00129 * $(dbh/2.54)^{1.76296}$ * $(3.28*ht)^{1.42782}$)	769
	Gleditsia triancanthos	9.1 - 98.3	=0.000489 * $dbh^{2.132}$ * $ht^{0.142}$	977
H	Gymnocladus dioicus	10.2 - 36.8	=0.000463 * $dbh^{1.545}$ * $ht^{0.792}$	929
E	Jacaranda mimosifolia	17.3 - 59.7	=0.0283168466(0.01131 * $(dbh/2.54)^{2.18578}$ * $(3.28*ht)^{0.54805}$)	609
I	Liquidambar styraciflua	14.0 - 54.4	=0.0283168466(0.01177 * $(dbh/2.54)^{2.31582}$ * $(3.28*ht)^{0.41571}$)	801
G	Magnolia grandiflora	14.5 - 74.2	=0.0283168466(0.00449 * $(dbh/2.54)^{2.07041}$ * $(3.28*ht)^{0.84563}$)	945
H	Pinus radiata	16.8 - 105.4	=0.0283168466(0.00533 * $(dbh/2.54)^{2.22681}$ * $(3.28*ht)^{0.66899}$)	705
T	Pistacia chinensis	12.7 - 51.3	=0.0283168466(0.00292 * $(dbh/2.54)^{2.19157}$ * $(3.28*ht)^{0.94367}$)	657
	Platanus acerifolia	15.5 - 73.9	=0.0283168466(0.01043 * $(dbh/2.54)^{2.43642}$ * $(3.28*ht)^{0.39168}$)	833
	Populus sargentii	6.4 - 136.7	=0.001906 * $dbh^{1.806}$ * $ht^{0.134}$	753
	Quercus ilex	12.7 - 52.1	=0.0283168466(0.00431 * $(dbh/2.54)^{1.82158}$ * $(3.28*ht)^{1.06269}$)	1186
	Quercus macrocarpa	10.9 - 100.1	=0.000169 * $dbh^{1.956}$ * $ht^{0.842}$	993
	Tilia cordata	11.2 - 64.5	=0.000945 * $dbh^{1.617}$ * $ht^{0.59}$	673
	Ulmus americana	17.5 - 114.3	=0.0012 * $dbh^{1.696}$ * $ht^{0.405}$	865
	Ulmus parvifolia chinensis	17.3 - 55.9	=0.0283168466(0.01046 * $(dbh/2.54)^{2.32481}$ * $(3.28*ht)^{0.49317}$)	865
	Ulmus pumila	15.5 - 131.6	=0.000338 * $dbh^{0.855}$ * $ht^{2.041}$	865
	Zelkova serrata	14.5 - 86.4	=0.0283168466(0.00666 * $(dbh/2.54)^{2.36318}$ * $(3.28*ht)^{0.55190}$)	865

Table C.2. Dry weight biomass equations from the forest literature. Use constants to add roots, convert to carbon and CO_2. Biomass is reduced to 80% of original predicted value to account for less biomass in urban trees.



Spcode	**Botanic**	**Common**	**Model**	**Source and DBH Range**
ACRU	Acer rubrum	Red maple	$=(0.1970*(dbh^{2.1933}))*0.80$	Ter-Mikaelian, Nova Scotia 0-35 cm red maple
ACSA2	Acer saccharum	Sugar maple	$=(0.1791*(dbh^{2.3329}))*0.80$	Ter-Mikaelian, Maine 3-66 cm sugar maple
PRSE2	Prunus serotina	Black cherry	$=((0.0716*dbh^{2.6174}))*0.80$	Ter-Mikaelian, West VA 5-50 cm black cherry
QURU	Quercus rubra	Northern red oak	$=(0.1130*(dbh^{2.4572}))*0.80$	TerMikaelian, West VA 5-50 cm red oak
FRAM	Fraxinus americana	White ash	$=(0.1063*(dbh^{2.4798}))*0.80$	Ter-Mikaelian, West VA 5-50 cm white ash
TIAM	Tilia americana	American basswood	$=((0.0617*dbh^{2.5328}))*0.80$	Ter-Mikaelian, West VA 5-50 cm basswood
BENI	Betula nigra	River birch	$=(0.0692*(dbh^{2.6606}))*0.80$	Ter-Mikaelian, West VA 5-50 cm black birch
Palms	General palms	General palms	$=(6.0*ht(m)+0.8)+(0.8*ht(m)+0.9)$	Frangi and Lugo, 1985
Hardwoods	General hardwoods	General hardwoods	$=((EXP(-2.437+2.418*(LN(dbh)))+EXP(-3.188+2.226*(LN(dbh)))))*0.8$	Tritton and Hornbeck, Northeast, 10-50 cm

Appendix D CUFR Tree Carbon Calculator

D.1 Urban Forests and Climate Change

This appendix describes how to use the CUFR Tree Carbon Calculator (CTCC) to estimate the amount of biomass and carbon stored in a tree, as well as the amount sequestered annually. The CTCC provides information on the effects of tree shade on residential heating and cooling energy use for energy conservation trees. Portions of the CTCC are common to both the carbon storage and energy conservation projects; the latter has additional data and output requirements, which are denoted with "§" in the text that follows. Final sections describe the methods used to determine the values used in the CTCC for tree shade effects on heating and cooling and describe potential areas of uncertainty.

The CTCC is intended as "proof of concept" software that is still in the testing phase. It is useable for those with moderate experience with spreadsheet software, and is provided "as is" without warranty of any kind. A substantial effort would be required for its thorough development, testing and evaluation. It currently returns results for a single tree at a time, requiring that project totals be determined external to the calculator.

A note on units: Carbon reporting currently uses a hybrid of SI and English units, for example kg/MBtu and kg/gal (ARB 2007). The CTCC follows a similar convention. The most common unit for tree dbh measurement is inches, which is used in the CTCC, while outputs are given in kilograms.

D.2 Background

The CTCC is programmed in an Excel spreadsheet. It is designed to provide carbon-related information for a single tree located in one of six California climate zones. The user must enter information on the size or age of the tree and species for carbon storage. Additional inputs are required for an energy conservation project. CTCC outputs can be used to estimate GHG benefits for existing trees or to forecast future benefits.

Tree size data are based on growth curves developed from samples of about 900 street trees representing approximately 20 predominant species in each of the six regional reference cities. Biomass equations and calculations used in the CTCC to derive total CO_2 stored (freshweight), total aboveground stored (dry weight), and CO_2 sequestration are described in Appendix C. To determine effects of tree shade on building energy performance, over 12,000 simulations were conducted for each reference city using different combinations of tree sizes, locations, and building vintages. More detailed information on procedures can be found in each region's Community Tree Guide (McPherson et al. 1999, 2000, 2003, 2004).

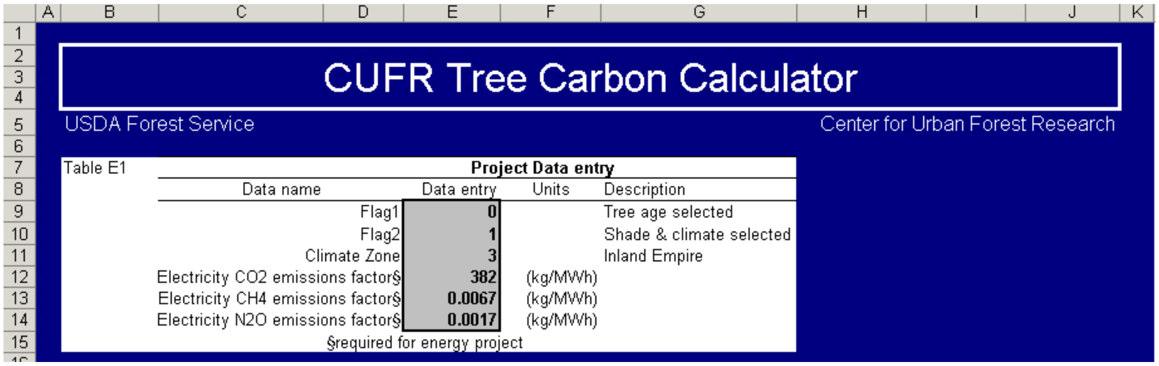
Users should recognize that conditions vary within regions, and data from the CTCC may not accurately reflect their rate of tree growth, microclimate, or building characteristics. When conditions are different it may be necessary to apply biomass equations manually using adjusted tree growth data and perform building energy simulations with modified weather and tree data to more accurately depict effects of trees on GHGs.

D.3 CTCC Step by Step Instructions

Start the CTCC by opening the ‘CarbonCalculatorNN.xls’ workbook. The associated files for each region (‘XXX carbon-biomass.xls’ and ‘XXXSim.xls’) must be located in the same folder and will load automatically. “NN” refers to the revision number (18 as of 1 June 2008).

D.3.1 Collecting and Entering Initial Project Data

Certain data apply to a GHG tree project as a whole. These data are entered into shaded areas in [CarbonCalculator]CTCC (**Figure D.1**).



CUFR Tree Carbon Calculator

USDA Forest Service

Center for Urban Forest Research

Table E1

Project Data entry

Data name	Data entry	Units	Description
Flag1	**0**		Tree age selected
Flag2	**1**		Shade & climate selected
Climate Zone	**3**		Inland Empire
Electricity CO2 emissions factor§	**382**	(kg/MWh)	
Electricity CH4 emissions factor§	**0.0067**	(kg/MWh)	
Electricity N2O emissions factor§	**0.0017**	(kg/MWh)	

§required for energy project

Figure D.1. Project-related data entry section of CTCC. Shaded areas are cells for data input. § required for energy project

The rows in the CTCC data entry section represent the following:

Flag1: *Age or DBH*. For new projects in which GHG benefits are being predicted into the future, age data should be used. For existing projects where trees have been measured, dbh data should be used. Refer to Appendix B for detailed instructions for determining dbh and age. Enter 1 to compute values based on dbh input or 0 to use tree age input.

Flag2: The CTCC can calculate the energy benefits based solely on shade or general climate benefits of trees can be included. Enter 0 to calculate shade benefits only. Enter 1 to calculate shade and climate benefits.

Climate zone: Identify which of 6 California regions applies to your project (**Figure D.2**). Region boundaries are approximate, and the climate of cities within each region can differ considerably. Match Cooling Degree Days and Heating Degree Days for the project location with those in **Table D.1** if in doubt. Selecting the appropriate region is important because site climate influences space heating and cooling requirements and potential energy savings from trees.

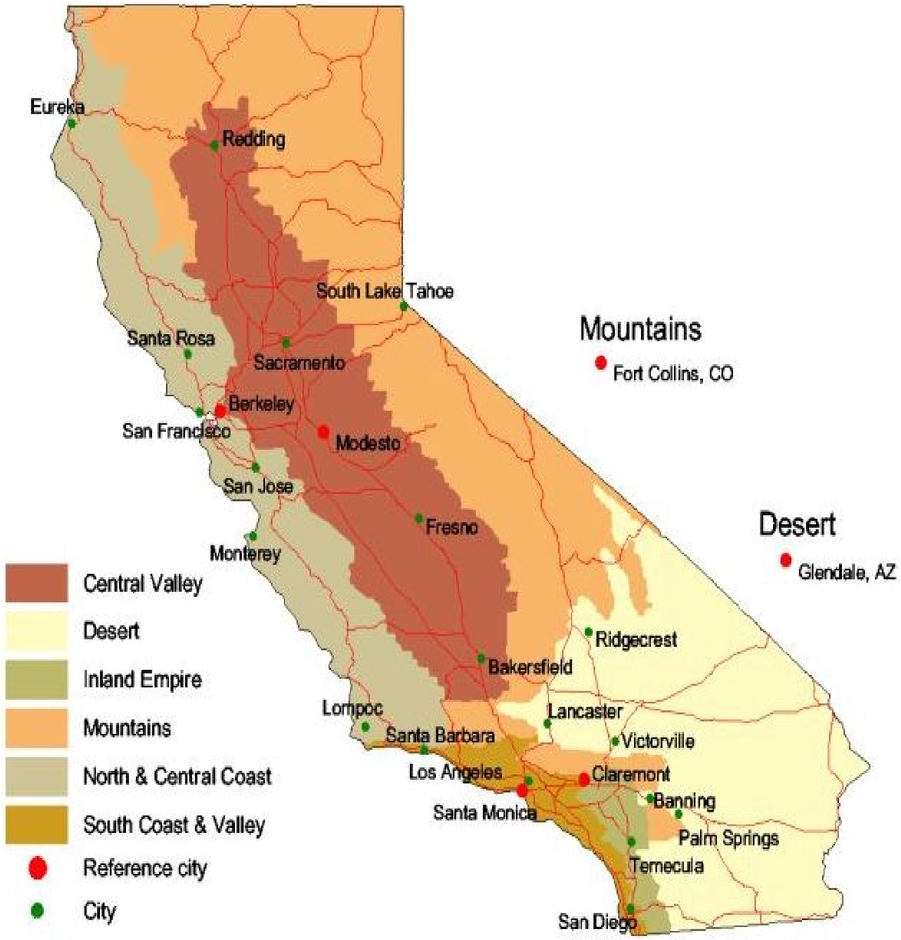


Figure D.2. California climate zones.

Table D.1. California regions for CUFR Tree Carbon Calculator.

Climate region	Reference City	CDD[1]	HDD[2]
North and Central coast	Berkeley	142	2862
South Coast	Santa Monica	679	1274
Inland Empire	Claremont	1863	1475
Central Valley	Modesto	1248	2666
Desert	Glendale, AZ	4364	1027
Mountains	Fort Collins, CO	696	6128

[1] CDD = Cooling Degree Days

[2] HDD = Heating Degree Days

Western Regional Climate Center 1971-2000 normals, 65°F baseline.

Emission factors: For energy conservation projects only, assign utility-specific emission factors for carbon dioxide, methane, and nitrous oxide for cooling (electricity). Electricity emission factors differ regionally because of utility-specific differences in the mix of fuels used to generate electricity. Contact your local electricity supplier to obtain the most accurate values for your location. Alternatively, electricity emission factors for California's major utilities are listed in **Table D.2** and utility service areas shown in

Figure D.3. Emission factors for space heating will differ depending on heating fuel type used in each building, hence are entered in the building data section that follows.

Table D.2. Electricity and natural gas emission factors (California Air Resources Board 2007).

Utility	Electrical generation Average emission factor (kg/MWh)			Natural gas Heating emission factor (kg/MBtu)			Fuel oil Heating emission factor (kg/MBtu)		
	CO_2	Methane	Nitrous Oxide	CO_2	Methane	Nitrous Oxide	CO_2	Methane	Nitrous Oxide
LADWP	727	0.0030	0.0017	53.1	0.0059	0.00010	73	0.0014	0.00010
SCE	483	0.0030	0.0017	53.1	0.0059	0.00010	73	0.0014	0.00010
SDG&E	511	0.0030	0.0017	53.1	0.0059	0.00010	73	0.0014	0.00010
PG&E	241[a]	0.0030	0.0017	53.1	0.0059	0.00010	73	0.0014	0.00010
California	395[a, b]	0.0030	0.0017	53.1	0.0059	0.00010	73	0.0014	0.00010

[a] results for PG&E include Sacramento Municipal Utility District (SMUD).
[b] Includes irrigation districts and municipal utilities.

Greenhouse gases covered by California's Global Warming Solutions Act (AB 32) are carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. Since the latter three account for only about 1.5% of total greenhouse gas emissions in the United States (EIA 2007) and represent over 25 different gases, they are excluded from the current analysis. Methane and nitrous oxide emissions are multiplied by their respective Global Warming Potentials (GWPs) (**Table D.3**) to obtain the equivalent CO_2 emissions.

Table D.3. 100-year GWP estimates of greenhouse gases (EIA 2007).

Gas	GWP
Carbon dioxide	1
Methane	23
Nitrous oxide	296

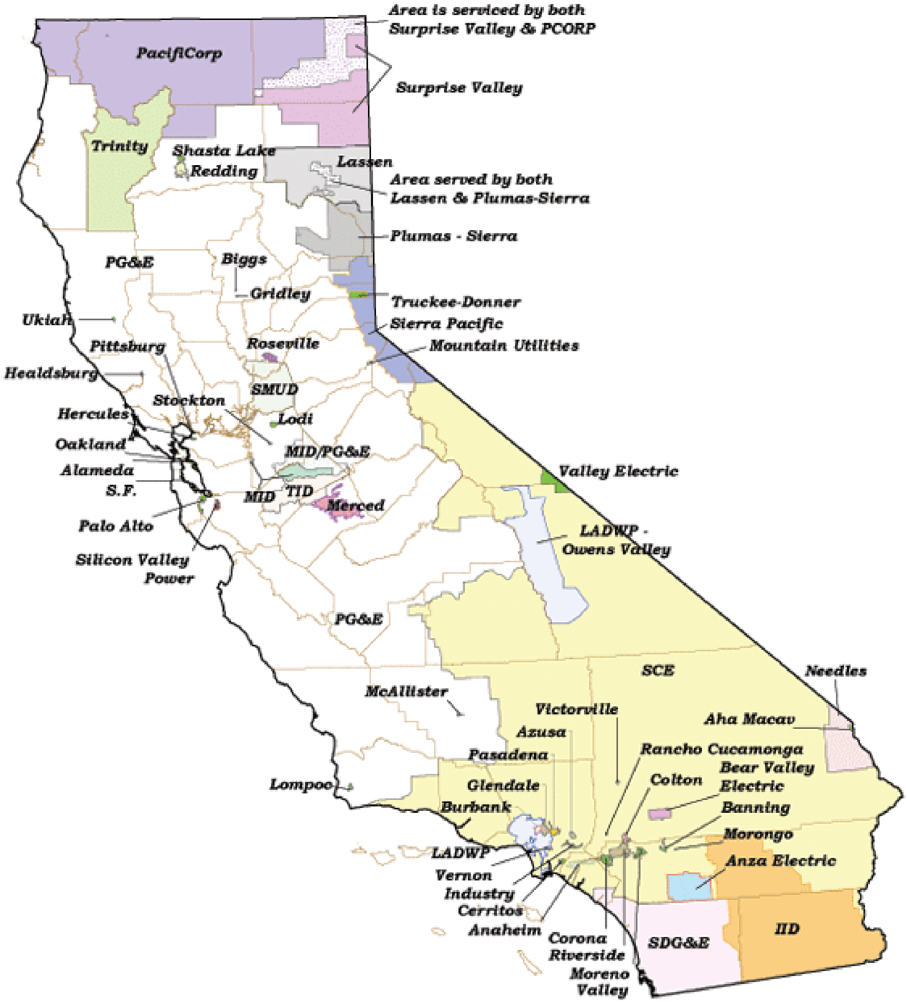
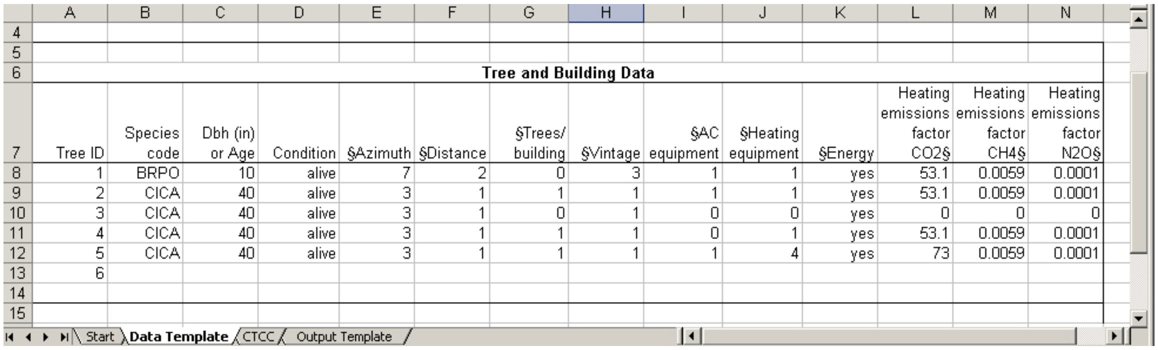


Figure D.3. California electric utility service areas (CEC 2007). *IID* Imperial Irrigation District, *LADWP* Los Angeles Dept. of Water and Power, *MID* Modesto Irrigation District, *PG&E* Pacific Gas & Electric, *SCE* Southern California Edison, *SDG&E* San Diego Gas & Electric, *SMUD* Sacramento Municipal Utility District, *SPP* Sierra-Pacific Power, *TID* Turlock Irrigation District.

D.3.2 Collecting Initial Tree Data

Data on individual trees are entered into the CTCC next. As the CTCC currently functions, trees must be entered one at a time and the results recorded by hand. To keep track of initial input data, we recommend the use of spreadsheet such as that show below (included in worksheet [CarbonCalculatorNN]Data Template) (**Figure D.4**).



Tree and Building Data

Tree ID	Species code	Dbh (in) or Age	Condition	§Azimuth	§Distance	§Trees/ building	§Vintage	§AC equipment	§Heating equipment	§Energy	Heating emissions factor CO2§	Heating emissions factor CH4§	Heating emissions factor N2O§
1	BRPO	10	alive	7	2	0	3	1	1	yes	53.1	0.0059	0.0001
2	CICA	40	alive	3	1	1	1	1	1	yes	53.1	0.0059	0.0001
3	CICA	40	alive	3	1	0	1	0	0	yes	0	0	0
4	CICA	40	alive	3	1	1	1	0	1	yes	53.1	0.0059	0.0001
5	CICA	40	alive	3	1	1	1	1	4	yes	73	0.0059	0.0001
6													

Figure D.4. Example template for compiling tree- and building-related data. § indicates fields for energy projects only.

The columns represent the following:

TreeID: This is a unique number assigned to each tree for use as individual tree identification. IDs from an existing tree inventory may be used.

Species Code: This is a 2 to 6 character code consisting of the first two letters of the genus name and the first two letters of the species name followed by two optional numbers to distinguish two species with the same four-letter code (USDA National Plants Database).

Age or DBH: For new projects in which GHG benefits are being predicted into the future, age data should be used. For existing projects where trees have been measured, dbh data should be used. Refer to Appendix B for detailed instructions for determining dbh and age.

Condition: Record whether tree is dead or alive. The carbon stored in dead trees is eligible to be reported or to be used for wood products or bioenergy projects. Only live trees, however, are eligible for energy conservation projects.

Azimuth: For energy conservation projects, record the direction that the tree lies from the nearest building. Azimuth is taken with compass, as in

Figure D.5, the coordinate of the tree is taken from imaginary lines extending from walls of the nearest conditioned space (heated or air conditioned space—may not be same address as tree location):

1: N = North (337.5-22.5°)
2: NE = Northeast (22.5-67.5°)
3: E = East (67.5-112.5°)
4: SE = Southeast (112.5-157.5°)
5: S = South (157.5-202.5°)
6: SW = Southwest (202.5-247.5°)
7: W = West (247.5-292.5°)
8: NW = Northwest (292.5-337.5°)
9: NA = No building for reference (>18 m setback)

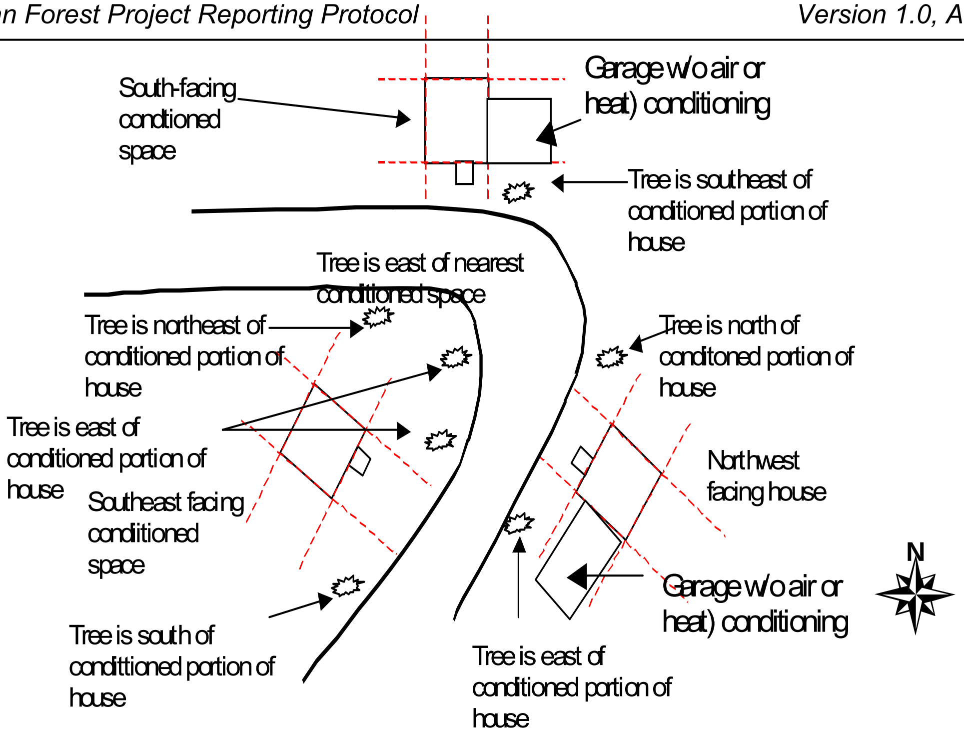


Figure D.5. How orientation from tree to building should be measured. Shows imaginary lines extending from walls and associated tree orientation.

Distance: For energy conservation projects, record distance from tree to nearest air conditioned/heated space. Evaluate as:

1: 0-8 m (0-25 ft, or ‘adjacent’)
2: 8.1-12 m (25.1-40 ft, or ‘near’)
3: 12.1-18 m (40.1-60 ft, or ‘far’)
4: >18 m (>60 ft)

Trees/building: For energy conservation projects, record the presence of existing trees within 18 m (60 ft) of the building. Count only trees greater than 12 m (40 ft) tall, or capable of growing to this size, located within 18 m (60 ft) of the east-, south-, or west-facing walls. Existing trees include project trees that have already been added to the data base. If such a tree already exists around a property, the building is considered “shaded” and additional project trees will not be considered to have an energy benefit. Only their carbon storage benefit can be considered.

Vintage: For energy conservation projects, assign the correct vintage to each eligible residential building. A vintage consists of buildings of similar age, construction type, floor area, and energy efficiency characteristics. Detailed information on each vintage is listed below in Section D.4. Although the exact characteristics of each vintage change regionally, the names remain constant and general distinguishing features are:

1: Pre-1950 vintage - low insulation levels, small conditioned floor area (CFA), large window area:CFA ratios,
2: 1950-1980 vintage - more ceiling insulation, lower window area:CFA ratios,
3: Post-1980 vintage - more wall insulation, more CFA, lower window area:CFA ratios.

AC equipment: For energy conservation projects, identify the type of air conditioning equipment in the building nearest to the tree. Choices for air conditioning equipment are:

0: None
1: Central air/heat pump
2: Evaporative cooler
3: Wall/window unit

Heating equipment: For energy conservation projects, identify the type of heating equipment in the building nearest to the tree. Choices for heating equipment are:

0: None
1: Natural gas
2: Oil/other fossil
3: Electric resistance (not currently implemented)
4: Heat pump

Energy: Based on the condition of the tree and the presence of additional existing trees, determine whether the tree qualifies as eligible for an energy conservation project.

Heating emission factors: In contrast to electricity emission factors, which should be constant across a project, emission factors for space heating will differ depending on heating fuel type used in each building. See **Table D.2** for the most common heat sources.

Once tree data have been collected, each tree can be entered individually into the CTCC.

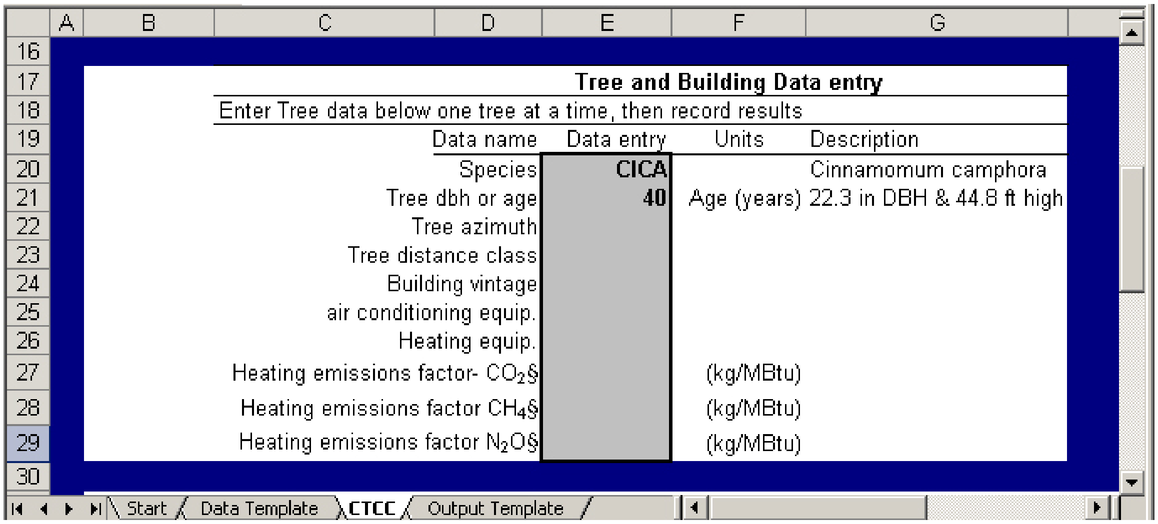
D.3.3 Determining Tree Biomass and Carbon Storage

Instructions for using the CTCC to measure carbon storage by project trees are given below. For instructions on using the CTCC to estimate energy conservation benefits at the same time, see **D.3.4** below.

1. Enter species and dbh or age data (e.g. as recorded in **Figure D.4**) for one tree into the CTCC Tree and Building data entry section (**Figure D.6**). Entries related to energy conservation are blank. **Figure D.7** shows the CTCC output for carbon storage.

2. Record CO_2 sequestration (lb/tree/year), total CO_2 stored (lb/tree), and aboveground biomass (dry weight, lb/tree) from **Figure D.7** in a separate location. For example, **Figure D.8** is included as an optional form in worksheet [CarbonCalculatorNN]Output Template.

3. Calculate emission reductions for all project trees by repeating steps 1 through 3 above for each tree, recording the results as illustrated in **Figure D.8**, which facilitates totaling results over all trees for the project.

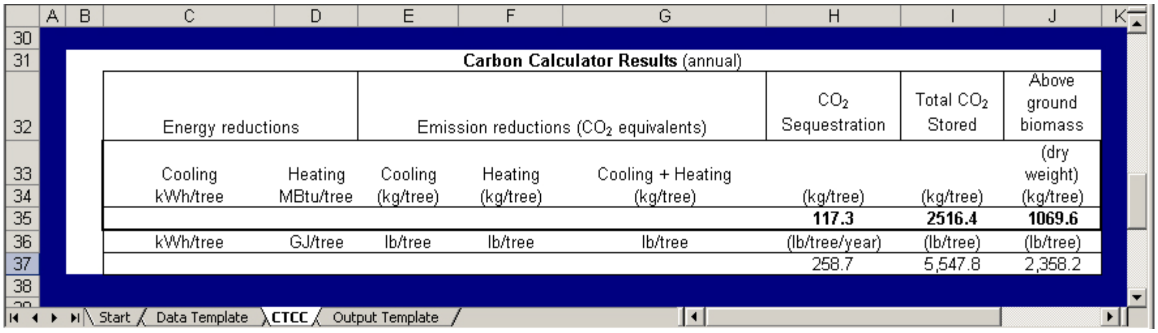


Tree and Building Data entry

Enter Tree data below one tree at a time, then record results

Data name	Data entry	Units	Description
Species	**CICA**		Cinnamomum camphora
Tree dbh or age	**40**	Age (years)	22.3 in DBH & 44.8 ft high
Tree azimuth			
Tree distance class			
Building vintage			
air conditioning equip.			
Heating equip.			
Heating emissions factor- CO_2§		(kg/MBtu)	
Heating emissions factor CH_4§		(kg/MBtu)	
Heating emissions factor N_2O§		(kg/MBtu)	

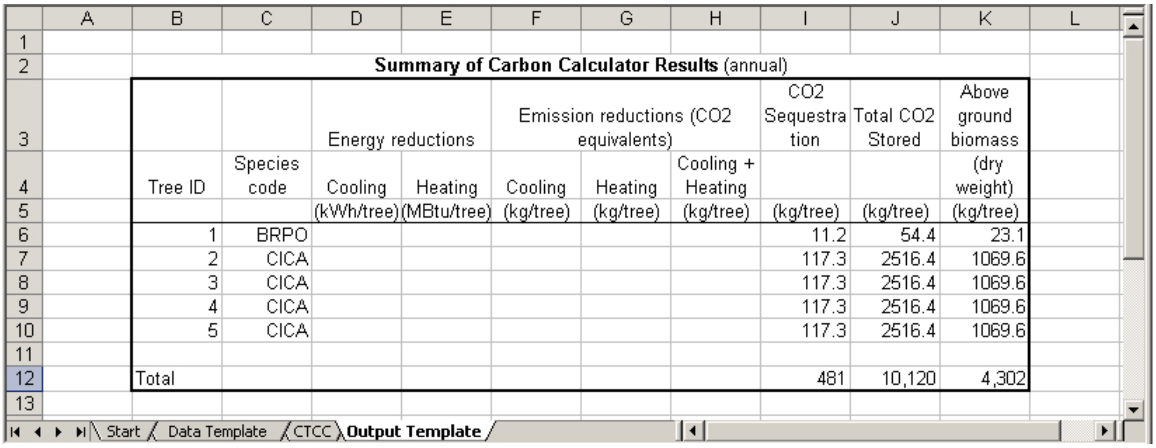
Figure D.6. Tree-related data entry section for carbon storage project only (shaded area of [CarbonCalculatorNN.xls]CTCC).



Carbon Calculator Results (annual)

Energy reductions		Emission reductions (CO_2 equivalents)			CO_2 Sequestration	Total CO_2 Stored	Above ground biomass
Cooling kWh/tree	Heating MBtu/tree	Cooling (kg/tree)	Heating (kg/tree)	Cooling + Heating (kg/tree)	(kg/tree)	(kg/tree)	(dry weight) (kg/tree)
					117.3	**2516.4**	**1069.6**
kWh/tree	GJ/tree	lb/tree	lb/tree	lb/tree	(lb/tree/year)	(lb/tree)	(lb/tree)
					258.7	5,547.8	2,358.2

Figure D.7. Output section of CTCC: carbon storage project only, CICA, year 40 ([CarbonCalculatorNN.xls]CTCC).



Summary of Carbon Calculator Results (annual)

Tree ID	Species code	Energy reductions Cooling (kWh/tree)	Heating (MBtu/tree)	Emission reductions (CO2 equivalents) Cooling (kg/tree)	Heating (kg/tree)	Cooling + Heating (kg/tree)	CO2 Sequestration (kg/tree)	Total CO2 Stored (kg/tree)	Above ground biomass (dry weight) (kg/tree)
1	BRPO						11.2	54.4	23.1
2	CICA						117.3	2516.4	1069.6
3	CICA						117.3	2516.4	1069.6
4	CICA						117.3	2516.4	1069.6
5	CICA						117.3	2516.4	1069.6
Total							481	10,120	4,302

Figure D.8. Example output summary table for results from CTCC for carbon storage project only.

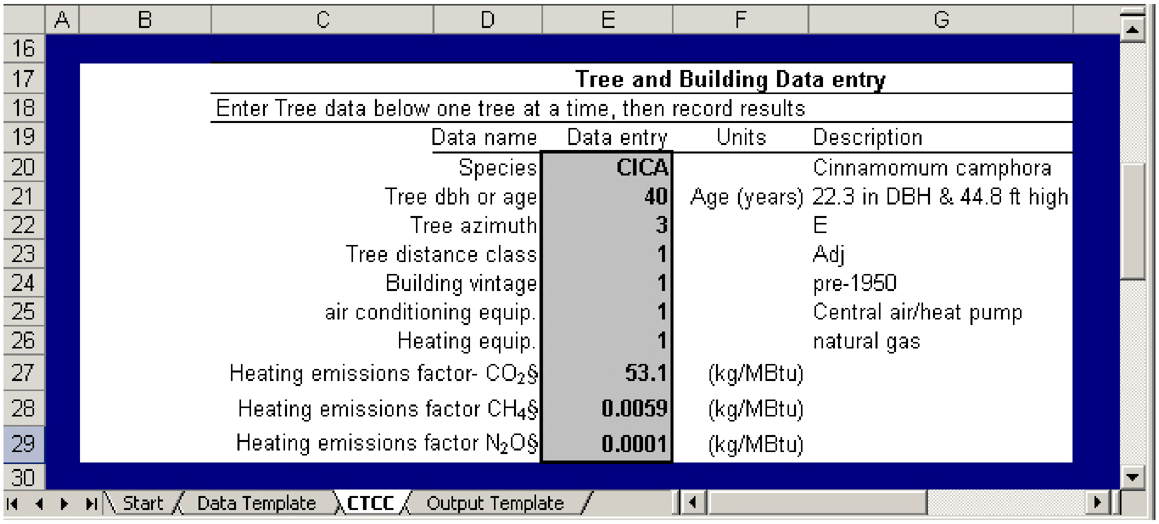
D.3.4 Determining Reduction in GHG Emissions from Tree Shade and Carbon Storage

If carbon storage benefits and energy conservation benefits should both be calculated, data are entered in the CTCC as indicated below.

1. Enter tree and building data for one tree into the Carbon Calculator (**Figure D.9**).

2. Record tree shade effects on building heating (kBtu/tree/year) and cooling (kWh/tree/year) from **Figure D.10** in another location. For example, as in **Figure D.11**. Tree shade effects on energy are converted to mass of CO_2 by multiplying energy units (kWh and KBtu) by utility-specific emission factors in the CTCC.

3. Calculate emission reductions for all project trees by repeating steps 1 to 2 described above for each time interval, then recording the results into a summary table like that illustrated in **Figure D.11**, which facilitates totaling results over all trees for the project.

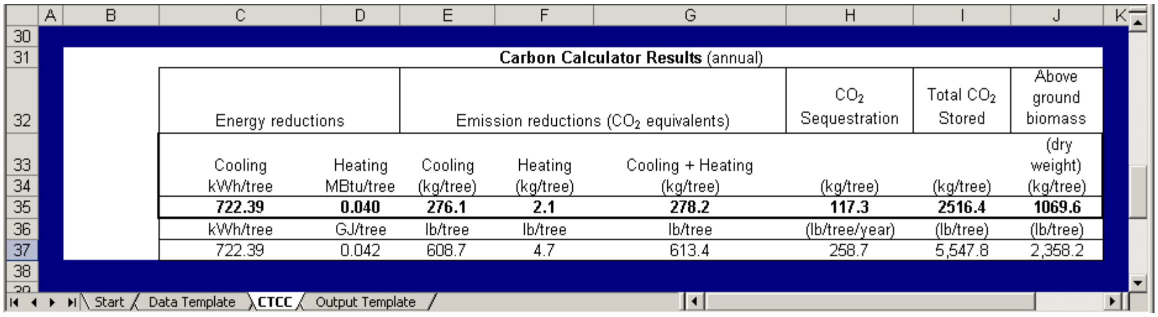


Tree and Building Data entry

Enter Tree data below one tree at a time, then record results

Data name	Data entry	Units	Description
Species	CICA		Cinnamomum camphora
Tree dbh or age	40	Age (years)	22.3 in DBH & 44.8 ft high
Tree azimuth	3		E
Tree distance class	1		Adj
Building vintage	1		pre-1950
air conditioning equip.	1		Central air/heat pump
Heating equip.	1		natural gas
Heating emissions factor- CO_2§	53.1	(kg/MBtu)	
Heating emissions factor CH_4§	0.0059	(kg/MBtu)	
Heating emissions factor N_2O§	0.0001	(kg/MBtu)	

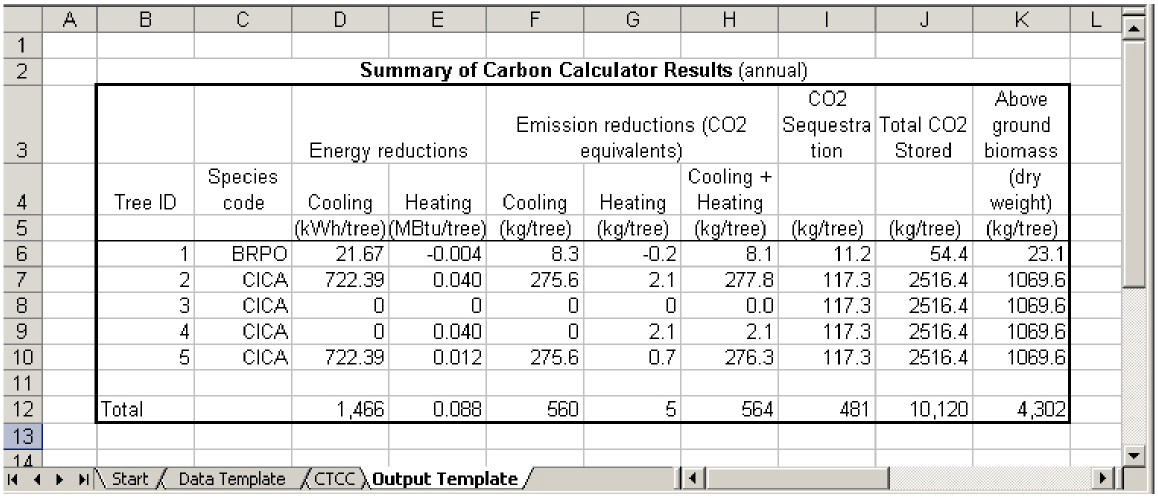
Figure D.9. Tree- and building-related data entry section for energy conservation project (shaded areas of [CarbonCalculatorNN.xls]CTCC. Data for carbon storage project are included as a subset.



Carbon Calculator Results (annual)

Energy reductions		Emission reductions (CO_2 equivalents)			CO_2 Sequestration	Total CO_2 Stored	Above ground biomass
Cooling kWh/tree	Heating MBtu/tree	Cooling (kg/tree)	Heating (kg/tree)	Cooling + Heating (kg/tree)	(kg/tree)	(kg/tree)	(dry weight) (kg/tree)
722.39	**0.040**	**276.1**	**2.1**	**278.2**	**117.3**	**2516.4**	**1069.6**
kWh/tree	GJ/tree	lb/tree	lb/tree	lb/tree	(lb/tree/year)	(lb/tree)	(lb/tree)
722.39	0.042	608.7	4.7	613.4	258.7	5,547.8	2,358.2

Figure D.10. Output section of CTCC: energy conservation and carbon storage project ([CarbonCalculatorNN.xls]CTCC) for tree in **Table D.9**.



Summary of Carbon Calculator Results (annual)

Tree ID	Species code	Energy reductions: Cooling (kWh/tree)	Energy reductions: Heating (MBtu/tree)	Emission reductions (CO2 equivalents): Cooling (kg/tree)	Emission reductions (CO2 equivalents): Heating (kg/tree)	Emission reductions (CO2 equivalents): Cooling + Heating (kg/tree)	CO2 Sequestration (kg/tree)	Total CO2 Stored (kg/tree)	Above ground biomass (dry weight) (kg/tree)
1	BRPO	21.67	-0.004	8.3	-0.2	8.1	11.2	54.4	23.1
2	CICA	722.39	0.040	275.6	2.1	277.8	117.3	2516.4	1069.6
3	CICA	0	0	0	0	0.0	117.3	2516.4	1069.6
4	CICA	0	0.040	0	2.1	2.1	117.3	2516.4	1069.6
5	CICA	722.39	0.012	275.6	0.7	276.3	117.3	2516.4	1069.6
Total		1,466	0.088	560	5	564	481	10,120	4,302

Figure D.11. Example output summary table for results from CTCC for combined carbon storage/energy conservation project.

D.4 Methods Used to Calculate Tree Shade Effects on Cooling and Heating

Calculations of annual building energy use per residential unit (unit energy consumption [UEC]) were based on computer simulations that incorporated building, climate, and shading effects, following methods outlined by McPherson and Simpson (1999). Changes in UECs due to the effects of trees (ΔUECs) were calculated on a per tree basis by comparing results before and after adding trees. Building characteristics (e.g. cooling and heating equipment saturations, floor area, number of stories, insulation, window area, etc.) are differentiated by a building's vintage, or age of construction: pre-1950, 1950–1980, and post-1980. For example, all houses from 1950–1980 vintage are assumed to have the same floor area, and other construction characteristics. Shading effects for approximately 20 of the most common tree species were simulated in each climate zone for three tree-to-building distances (0–20 ft, 20–40 ft, 40–60 ft), eight orientations (cardinal and intercardinal points of the compass) and for nine tree sizes. It was assumed that street trees greater than 60 ft from buildings provided no direct shade on walls and windows and hence no energy-related benefit.

The shading coefficients of the trees in leaf (gaps in the crown as a percentage of total crown silhouette) were estimated using a photographic method that has been shown to produce good estimates (Wilkinson 1991). Crown areas were obtained using the method of Peper and McPherson (2003) from digital photographs of trees from which background features were digitally removed. Values for tree species that were not sampled, and leaf-off values for use in calculating winter shade, were based on published values where available (McPherson 1984; Hammond et al. 1980). Where published values were not available, visual densities were assigned based on taxonomic considerations (trees of the same genus were assigned the same value) or observed similarity to known species. Foliation periods for deciduous trees were obtained from the literature (McPherson 1984; Hammond et al. 1980) and adjusted for each climate zone based on consultation with forestry supervisors and local nursery representatives.

Prototype buildings were simulated to represent pre-1950, 1950–1980, and post-1980 construction practices for each climate zone (**Table D.4.4**). Building footprints were modeled as square, which was found to reflect average impacts for a large number of buildings (Simpson 2002). Buildings were simulated with 1.5 ft overhangs. Blinds had a visual density of 37%, and were assumed to be closed when the air conditioner was operating. Thermostat settings were 78°F for cooling and 68°F for heating, with a 60°F night setback in winter. Unit energy consumptions are adjusted in the CTCC to account for different types of heating and cooling equipment (**Table .5**) and efficiencies (

Table.6).

Table D.4. Building data by climate zone (Ritschard et al. 1992). CFA is conditioned floor area, and SEER (Seasonal Energy Efficiency Ratio) and AFUE (Annual Fuel Utilization Efficiency) are measures of heating and cooling equipment efficiencies.

			CFA	**Glazing**		**Wall**	**Foundation**	**R Values**				**Cooling**	**Heating**
Climate Region	**Vintage**	**Stories**	**(m^2)**	**(m^2)**	**panes**	**Type**	**Type**	**Wall**	**Ceiling**	**Floor**	**Found.**	**SEER**	**AFUE**
Mountains	Pre 1950	1	90.6	16.4	2	Wood	Basement	7	11	0	0	8	0.75
	1950 80	1	100.3	18.2	2	Brick	Slab	7	11	0	0	8	0.75
	Post 1980	2	192.3	24.4	2	Wood	Basement	13	31	11	0	10	0.78
North, Central & south Coast	Pre 1950	1	130.1	22.7	1	Wood	Crawl	7	7	0	0	8	0.75
	1950 80	1	129.1	22.5	1	Stucco	Crawl	7	11	0	0	8	0.75
	Post 1980	2	192.3	30.2	2	Stucco	Slab	11	25	0	0	10	0.78
Central Valley	Pre 1950	1	90.6	16.4	2	Wood	Basement	7	11	0	0	8	0.75
	1950 80	1	100.3	18.2	2	Brick	Slab	7	11	0	0	8	0.75
	Post 1980	1	154.2	16.6	2	Stucco	Slab	13	29	0	5	10	0.78
Desert	Pre 1950	1	90.6	16.4	2	Wood	Basement	7	11	0	0	8	0.75
	1950 80	1	100.3	18.2	2	Brick	Slab	7	11	0	0	8	0.75
	Post 1980	1	154.2	16.6	2	Stucco	Slab	13	27	0	0	10	0.78

Weather data for typical meteorological years (TMY2) from each climate zone were used (National Solar Radiation Data Base 2006).

Table D.5. Cooling equipment factors.

	Building vintage		
	pre-1950	**1950-1980**	**post-1980**
Central air/heat pump	1	1	1
Evaporative cooler	0.33	0.33	0.33
Window/Wall unit	0.25	0.25	0.25
None	0	0	0

Table D.6. Heating and cooling equipment efficiencies.

	Building vintage		
	pre-1950	**1950-1980**	**post-1980**
Natural gas	1	1	1
Heat pump	0.110	0.115	0.098
Electric resistance	0.220	0.229	0.229
None	0	0	0

D.4.1 Single-Family Residence Adjustments

Unit energy consumptions for simulated single family residences were adjusted for type and saturation of heating and cooling equipment, and for various factors (F) that modify the effects of shade and climate on heating and cooling loads. For cooling we have:

$$\Delta UEC_c = \Delta UEC^{raw}_c \times F_c \qquad \text{[Eq.1]}$$

where

$F_c = F_{c\_equipment} \times F_{adjacent\ shade} \times F_{multiple\ tree}$

$F_{c\_equipment} = Sat_{CAC} + Sat_{window} \times 0.25 + Sat_{evap} \times 0.33$

For heating we have:

$$\Delta UEC_h = \Delta UEC^{raw}_h \times F_h \qquad \text{[Eq.2]}$$

where

$F_h = F_{h\_equipment} \times F_{adjacent\ shade} \times F_{multiple\ tree}$

$F_{h\_equipment} = Sat_{NG}$

Total change in energy use for a particular land use is found by multiplying the change in UEC per tree by the number of trees (*N*):

$$\text{Total change} = N \times \Delta UEC_x \qquad \text{[Eq.3]}$$

Where subscript *x* refers to cooling or heating.

Estimated shade savings for all residential structures could be adjusted to account for shading of neighboring buildings and for overlapping shade from trees adjacent to one another. Homes adjacent to those with shade trees may benefit from the trees on the neighboring properties. For example, 23% of the trees planted for the Sacramento Shade program shaded neighboring homes, resulting in an additional estimated energy savings equal to 15% of that found for program participants, which gives $F_{adjacent\ shade} \approx 1.15$. In addition, shade from multiple trees may overlap, resulting in less building shade from an added tree than would result if there were no existing trees. Simpson (2002) estimated that the fractional reductions in average cooling and heating energy use were approximately 6% and 5% percent per tree, respectively, for each tree added after the first. Simpson (1998) also found an average of 2.5 to 3.4 existing trees per residence in Sacramento. A multiple tree reduction factor of 85% is equivalent to approximately three existing trees per residence. Since these factors are difficult to assess and approximately compensating, it was assumed in the analysis that $F_{adjacent\ shade} \times F_{multiple\ tree} = 1.0$.

Cooling and heating effects are reduced based on the type of air conditioning or heating equipment and vintage. Equipment factors of 33 and 25% were assigned to homes with evaporative coolers and room air conditioners, respectively. These factors were combined with equipment saturations to account for reduced energy use and savings compared to those simulated for homes with central air conditioning ($F_{c\_equipment}$).

In addition to localized shade effects, which are assumed to accrue only to trees within 60 ft of buildings, lowered air temperatures and wind speeds due to neighborhood tree cover (referred to as climate effects) produce a net decrease in demand for summer cooling and winter heating. Reduced wind speeds by themselves may increase or decrease cooling demand, depending on the circumstances. To estimate climate effects on energy use, air temperature and wind speed reductions were estimated as a function of neighborhood canopy cover from published values following McPherson and Simpson (1999), then used as input for the building energy use simulations described earlier. Peak summer air temperatures were assumed to be reduced by 0.2 °F for each percentage increase in canopy cover. Wind speed reductions were based on the change in total tree plus building canopy cover resulting from the addition of the particular tree being simulated (Heisler 1990). An effective lot size (actual lot size plus a portion of adjacent street and other rights-of-way) of 10,000 ft^2 was assumed, and one tree on average was assumed per lot.

D.5 Initial Uncertainty Analysis

This initial uncertainty analysis estimates standard errors in CTCC's estimates of CO_2 emission reductions due to uncertainty in the emission factor, interpolation, and energy analysis (σ_e, σ_f, and σ_E). While a complete analysis of these errors is not possible here, preliminary estimates are given based on the following analysis.

Greater uncertainty is involved with default emission factors (σ_e) supplied by the CTCC than for locally derived values, since default factors are based on past data, and reflect only the largest utility service areas in the state. We assume a relative standard error (σ_e/e) of ±10% for default factors, and ±5% when locally derived data are utilized.

Uncertainty related to interpolation (σ_f) results from differences between the functional form used for interpolation here (linear) and the unknown form, a function of DBH or time. Empirical curve fitting could be used to reduce interpolation error, tested with additional between-class simulation runs. For now it is assumed based on the observed curve shapes that this relative error is ±10%. Overall uncertainty is relatively insensitive to the value selected.

Due to the many inputs and complexities of the building energy simulation modeling, which includes tree and building factors, σ_E is the most difficult standard error to quantify. Some of these factors, such as occupant behavior, are extremely difficult to quantify or verify. That being said, studies have been reported that deal with this issue, including one that compares actual measurements with simulated results.

We know of only one instance where simulations of energy savings effects of trees were compared to measurements. Akbari et al. (1997) made detailed measurements of two homes with and without 16 containerized trees about 2.4 to 6 m high shading south- and west-facing walls and windows. Measured savings were 47 and 26% over approximately 100 day summer measurement periods in Sacramento, California. Computer simulations were found to consistently underestimate the measured savings by a factor of two.

Complete calibration of the model was not one of the objectives of the study, so the exact cause(s) of the discrepancies were not elucidated. Initial indications based on the limited data available are that simulated energy savings from shade trees may be conservative estimates of actual savings.

As a preliminary estimate of the relative error in the building energy simulation modeling we use the value from Hildebrandt and Sarkovich (1998) of ±25%, recognizing that additional analysis will be necessary for individual consideration of many factors involved.

These preliminary estimates of relative standard error of $\sigma_e/e = 10\%$, $\sigma_f/f = 10\%$, and $\sigma_E/E = 25\%$ were substituted into an equation to calculate an initial estimate of the error in reduced CO_2 emissions. This resulting error will depend on the relative size of terms in the equation, and particularly on the relative size of cooling savings compared to heating penalty. Typical errors appear to be about 30%, but can be larger if increased emissions from heating become similar in size to the reduced emissions from heating, e.g. $e_1E_{n,}1 \approx e_2E_{n,2}$. Of course, in the latter case the net change in emissions becomes small, as does the magnitude of the error.

Appendix E Performance Standard Background Information

The performance standard data were collected and compiled by the USFS Center for Urban Forestry Research (CUFR).

E.1 Municipalities

The performance standard is based on an analysis of 18 U.S. cities. The data were obtained as part of a separate research project conducted by the CUFR.[6] The sample cities represent a variety of geographic regions, species mixes, age structures, and management regimes. Annual tree program data, including numbers of trees planted and removed annually, were reported by the urban forestry divisions of each municipality. According to the CUFR, the sample is representative of "higher performing" urban tree programs

Data for the 18 U.S. cities are shown in **Table E.1**. Population data were obtained from the U.S. Census Bureau where population estimates are made annually (http://www.census.gov/). Net tree gain (NTG) is calculated as the number of trees planted minus the number removed each year (a negative net tree gain means the city is losing trees on average). The percent change in tree population per year is NTG divided by the total tree population. The results show a broad range of NTG values for the 18 cities (-2500 NTG/yr to 1200 NTG/yr), and a broad range of tree population growth rates (from -0.37%/yr to 5.75%/yr). Bismark, ND, shows the largest rate of growth in the urban tree population of 5.75% per year, due to a high annual NTG for a moderately sized tree population. While Minneapolis, MN, has the largest tree population of all the cities sampled, it also has the largest negative rate of growth in the urban tree population of -1.25%/yr due to a large negative annual NTG.

Table E.1. Dataset for Municipality Tree Programs.

City	Population (# people)	Tree Population (# trees)	# trees planted per year	# trees removed per year	NTG (Net annual tree gain or loss)	Percent change in tree population per year
Bismarck, ND	56,234	17,821	1,725	701	1024	5.75%
Charleston, SC	104,883	15,244	500	70	430	2.82%
Stevens Point, WI	25,094	7,054	250	113	137	1.94%
Waukesah, WI	68,000	28,936	750	225	525	1.81%
Fargo, ND	90,800	45,000	1,048	260	788	1.75%
Davis, CA	58,600	24,000	480	125	355	1.48%
Modesto, CA	182,260	91,179	2500	1300	1200	1.32%
Ft Collins, CO	135,000	30,943	757	420	337	1.09%
Cheyenne, WY	53,011	17,010	319	143	176	1.03%
Charlotte, NC	597,308	85,146	700	350	350	0.41%
Denver, CO	385,000	102,000	2,500	2,084	416	0.41%
Glendale, AZ	220,000	21,986	200	195	5	0.02%

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[6] McPherson, E.G.; Simpson, J.R.; Peper, P.J.; Maco, S.E.; Xiao, Q. 2005. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry. 103(8): 411-416.

Glen Ellyn, IL	68,000	28,936	200	227	-27	-0.09%
Santa Monica, CA	92,578	29,229	148	185	-37	-0.13%
Colorado Springs, CO	385,000	102,000	1,400	1,700	-300	-0.29%
Lansing, MI	120,000	44,692	361	528	-167	-0.37%
Boulder, CO	103,216	35,802	85	330	-245	-0.68%
Minneapolis, MN	382,618	200,000	4,000	6,500	-2500	-1.25%

Figure E.1 shows the percent annual change in tree population for all 18 cities. Half of the cities are below and half are above the median value of 0.72%/yr (shown with a horizontal line). For comparison, the average value is 0.95%. The Reserve originally chose the median value as the performance threshold because it represents a level of performance that is well above average, considering that the dataset is comprised of high-performing cities. The median was chosen instead of the average because it evenly splits the data into two groups, whereas the average value is relatively high due to the high performance of Bismark, ND.

Several public comments suggested that a threshold set at the 50th percentile was too high and went well beyond a level consistent with above average performance. The Reserve evaluated setting the threshold at the 25th percentile instead, a value of -0.12%. Because a declining tree population is not considered best practice and the value is only slightly different from zero, the Reserve decided to revise the municipality performance threshold, setting it to a 0% growth rate in the urban tree population.

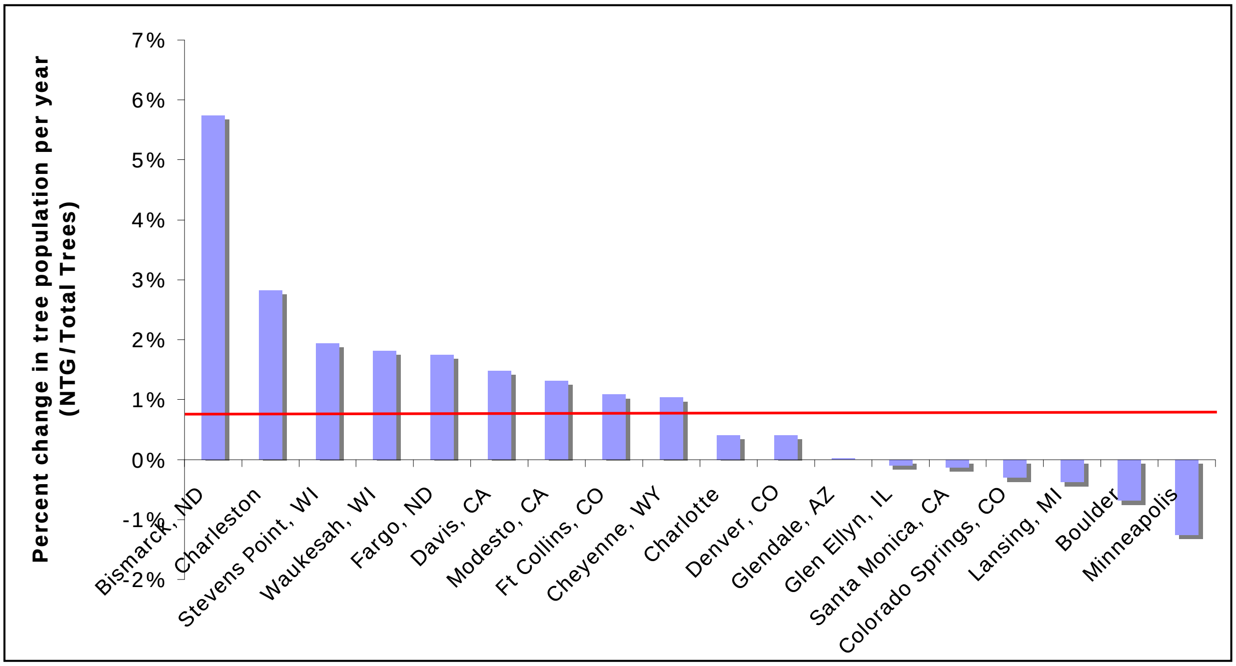

Figure E.1. Urban Tree Program Performance of Municipalities in Terms of NTG/Total Trees.

E.2 Educational Campuses

The performance standard is based on a survey of 12 California campuses conducted by CUFR. Over forty campuses were contacted for information on their tree programs.

Of those, twelve campuses responded (30%). Campus grounds managers provided information on the total number of campus trees, annual planting and removal rates, maintained campus area, among other things. Two of these campuses did not have data on the total tree population; thus, the performance standard threshold is based on data from 10 campuses.

The sample of campuses does not fully represent the configurations of all types of campus settings. For example, information is lacking for junior colleges, community colleges, and the smaller campuses of private universities. Respondents are likely to represent “higher performing” programs with accessible records on tree planting and removal rates. This performance standard may be updated in the future as information becomes available to include information from a larger and broader sample of campuses and campus-like settings (e.g. corporate headquarters, hospitals, high schools, industrial parks).

Data for the ten campuses are shown in **Table E.2**. California State University, Fresno has the highest rate of growth in their campus tree population at 6.32%/yr. University of California at San Diego was the only campus with a negative tree population growth rate of -0.14%.

Table E.2. Dataset for University Campus Tree Programs.

University	Area managed (acres)	Students	Number of managed trees on campus	Average plantings per year	Average removals per year	NTG	NTG/total trees
UC Santa Barbara	120	21,410	no inventory	38	15	23	no data
U of La Verne	32	4,000	no inventory	3	1	2	no data
CSU Fresno	350	22,000	3,750	300	63	237	6.32%
UC Berkeley	288	33,933	3,000	75	12	63	2.10%
Cal Poly, San Luis Obispo	200	20,000	3,000	75	25	50	1.67%
Cal Poly Pomona	1,600	17,500	3,300	35	7	28	0.85%
UC Davis	750	30,685	9,004	150	75	75	0.83%
Cal State Fullerton	200	37,000	2,500	20	12	8	0.32%
San Diego State U	250	35,000	10,000	25	5	20	0.20%
Stanford	4,000	15,000	45,000	200	150	50	0.11%
USC	170	33,000	4,647	15	13	2	0.04%
UC San Diego	1,076	27,500	220,000	100	400	-300	-0.14%

Figure E.2 shows the percent annual change in tree population for 10 campuses. Half of the campuses are below and half are above the median value of 0.58%/yr (show with a horizontal line). For comparison, the average value is 1.23%. The Reserve originally chose the median value as the performance standard threshold because it represents a level of performance that is well above average, considering that the dataset is comprised of high-performing campuses. Similar to the municipality dataset, the median was chosen instead of the average because it evenly splits the data into two groups, whereas the average value is relatively high due to the high performance of CSU Fresno.

Also similar to the municipality dataset, several public comments suggested that a threshold for educational campuses set at the 50the percentile was too high and went well beyond a level consistent with above average performance. The Reserve evaluated setting the threshold at the 25th percentile instead, in this case value of 0.13%. The Reserve decided to set the performance threshold for educational campuses to a 0% growth rate in the urban tree population, consistent with the municipality threshold, because the value is only slightly different from zero and would translates into an insignificant number of trees for most entities.

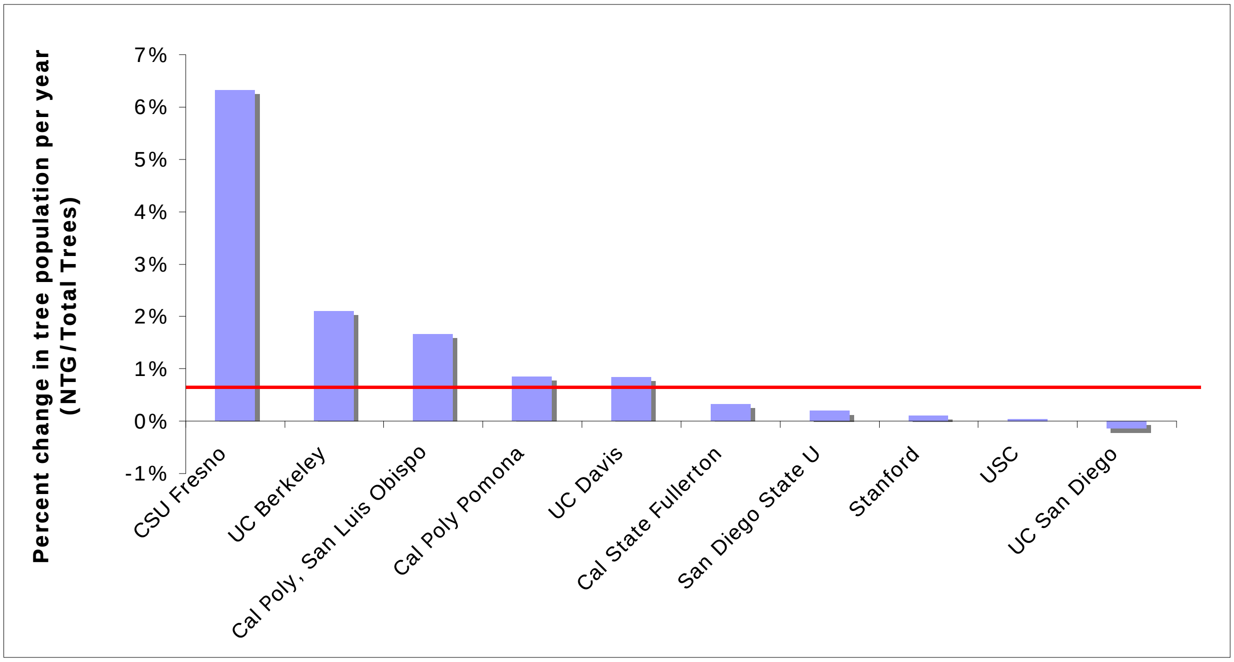

Figure E.2. Urban Tree Program Performance of Universities in Terms of NTG/Total Trees.

E.3 Utilities

CUFR surveyed 96 U.S. utilities with tree planting programs (there are 3,170 traditional utilities in the U.S.). Names were drawn from members of the American Public Power Association's TreePower program and from the National Arbor Day Foundation's Tree Line USA program. Both programs recognize utility companies that strive to foster community forests while providing a reliable source of power. Each utility was contacted by email and asked if they had a tree planting program that went beyond replacing removed trees and if so, how many trees each year were planted and how many residential customers they served. Twenty-eight utilities responded (30%). Of the 28, 15 had tree planting programs for purposes other than replacements. The number of trees planted annually ranged from 75 (City of Pasadena, CA, Water and Power) to approximately 15,000 (Sacramento, CA, Municipal Utility District [SMUD]). The number of trees planted annually per household ranged from 0.0005 (City Public Service of San Antonio (TX)) to 0.22381 (SMUD). Based on the entire dataset, the average annual planting rate was 0.015 tree/household. Excluding two outliers with very high planting rates (SMUD and Michigan's Traverse City Light & Power Department), the average number of trees planted per household for these high-performing programs was 0.004. Data were not available on the net tree gain for each utility.

The Reserve initially chose the average value, excluding outliers, as the performance threshold because it represented better than average performance, taking into account that the sample is of utilities with tree planting programs only. Public comments suggested that this threshold was too stringent and did not represent best practice among typical utilities because only a very small percentage of the total number of utilities in the U.S. have residential tree planting programs. Therefore, the Reserve removed the performance threshold for utilities and will consider all trees planted under these types of programs as additional.

Appendix F Co-Benefits

F.1 Energy Conservation

As part of a GHG tree planting project, trees may be strategically planted to reduce building energy consumption, resulting in a significant reduction in GHG emissions at the power plant. Because the emission reductions from energy conservation projects are difficult to verify, they cannot be registered but they can be reported to the Reserve as co-benefits.

It is important to note that the approach used here to estimate the GHG benefits of strategically planted trees considers the effects of tree shade on single family residential structures, as well as effects on air temperature and wind speed. The effects of trees on multi-family, commercial, industrial, and office buildings are not considered here. This approach does include the adverse effects of wintertime tree shade on emissions from energy consumed to heat homes. Therefore, trees in certain locations around buildings may increase GHG emissions.

F.1.1 Characterize and Quantify the Project Baseline

The energy conservation effects of strategically located trees are difficult to verify because many factors besides tree shade and climate modification influence building energy performance. Therefore, we assume that the energy conservation project baseline is 0, and simply calculate the estimated energy conservation effects of strategically located project trees that are deemed eligible energy conservation trees.

F.1.2 Characterize and Quantify Reduced Emissions

This section describes the general steps you will take to quantify the effects of project trees on energy conservation and GHG emissions, using a model designed by the Center for Urban Forest Research (CUFR Tree Carbon Calculator [CTCC]). Other models that relate energy conservation to tree shade may be used if available and approved by the Reserve. More detailed instructions for using the CTCC can be found in Appendix D.

It is important to note that all project trees may not be eligible to provide energy conservation benefits. Buildings with more than one existing tree greater than 12 m (40 ft) tall, or capable of growing to this size, located within 18 m (60 ft) of the east-, south-, or west-facing walls are considered "shaded" and are ineligible for inclusion in calculations of emission reductions from project activity.

Three types of data are required as input for the CTCC and most energy models: project, tree, and building. With these data you can determine the effects of each tree on building energy use.

Project data

1. Identify which of the 6 California regions apply to your project (Appendix D).
2. Assign utility-specific emission factors for carbon dioxide, methane, and nitrous oxide for both heating and cooling based on the fuel mix of your utility or power plant (Appendix D).

Tree data

1. For initial project reports, estimate the number of eligible trees of each species that will be alive for each year of the project. For annual project reports, determine the size (dbh and/or height) and species of all eligible project trees.
2. Determine tree location with respect to shaded residential buildings. Tree location data include:
    a. Distance from live tree to the eligible residential building is 3 to 6 m, 6 to 12 m, or 12 to 18 m (10-20, 20-40 or 40-60 ft).
    b. Azimuth classes for each tree are: N, NE, E, SE, S, SW, W and NW based on compass bearings.
3. Record the number of existing trees greater than 12 m (40 ft) tall, or capable of growing to this size, located within 18 m (60 ft) of the east-, south-, or west-facing walls. The presence of more than one such existing tree renders project trees within 18 m (60 ft) of the same structure ineligible for energy conservation GHG benefits.

Building data

1. Determine the vintage of each eligible residential building. General distinguishing features include:
    a. Pre-1950 vintage - low insulation levels, small conditioned floor area (CFA), large window area:CFA ratios,
    b. 1950-1980 vintage - more ceiling insulation, lower window area:CFA ratios, and
    c. Post-1980 vintage - more wall insulation, more CFA, lower window area:CFA ratios.
2. Determine the heating and cooling equipment type for each eligible building
    a. Choices for air conditioning equipment are:
        i. None
        ii. Central air/heat pump
        iii. Evaporative cooler
        iv. Wall/window unit
    b. Choices for heating equipment are:
        i. None
        ii. Natural gas
        iii. Oil/other fossil
        iv. Electric resistance
        v. Heat pump

Input the above data into the CTCC to determine effects on building energy use and GHG emission reductions. Divide results by 1,000 to convert kilograms into metric tons.

F.2 Displacing GHG Emissions Through Bioenergy

Bioenergy projects, which use tree residue as feedstock for a power plant, are another potential measure for reducing atmospheric GHG if the tree biomass replaces fossil fuel sources such as coal.

Because these emission reductions are difficult to verify they cannot be registered at this time, but they can be reported to the Reserve. Reporting these benefits may be of value to potential buyers in the future, and will give a more complete view of the value of your project.

F.2.1 Characterize and Quantify the Project Baseline

Characterizing a baseline for bioenergy projects is not straightforward. There are several problems with verifying displaced emissions from utilization of urban tree residue. Fuel mixes and associated emission factors are constantly changing as utilities purchase power, take plants off-line for maintenance, bring new plants on-line, and switch fuels in response to supply, demand, and costs. For the purposes of estimating the potential contribution that your project can have in terms of bioenergy, assume that the bioenergy project baseline is 0 because burning biomass is considered zero emitting.

F.2.2 Characterize and Quantify Displaced Emissions

Provide a detailed description of total bioenergy conversion following these steps:

1. For the initial project report, estimate mortality and the number and size of trees that will be removed for each year of the project. For annual project reports, determine the number of trees removed by tree type or species.

2. Calculate total aboveground biomass by volume (m^3): Use dbh (and height) data and allometric equations for different tree species (Appendix C).

3. Convert volume (m^3) into freshweight biomass (kg): multiply volume by a conversion factor for each species (kg/m^3).

4. Convert freshweight biomass to dry weight (DW) biomass (kg): multiply freshweight biomass (kg) for hardwoods and softwoods by 0.56 and 0.48, respectively, to derive DW based on average moisture content of the species.

5. As an alternative to steps 2-4, use the CUFR Tree Carbon Calculator (Appendix D) and enter tree size (dbh) or age to determine aboveground DW biomass per tree (kg).

6. Calculate the heat energy stored in the wood biomass (Btu): multiply the DW biomass by the heating value of wood (19,900 Btu/kg for softwoods and 18,960 Btu/kg for hardwoods) (Ragland et al. 1991).

7. Identify the biopower plant’s heat rate (Btu/kWh of electricity): The heat rate is the biopower plant’s efficiency of converting biomass to energy and depends on the type of technology and size of the facility.

8. Calculate annual electricity generation from the wood biomass (kWh): Divide the wood biomass heating value (Btu) from step 6 by the biopower plant’s heat rate (Btu/kWh) from step 7.

9. Convert from kWh to MWh: divide by 1,000.

10. Calculate emissions displaced (t): Identify the utility-specific GHG emission factors (t/MWh) for the energy that is being displaced and multiply them by the annual electricity generation from wood biomass (MWh) from step 9.

11. Convert all displaced GHG emissions to their CO_2 equivalents.

Appendix G Protocol Contributors

The Urban Forest Protocol is the result of an extensive stakeholder-driven process involving multiple committees comprised of a diversity of participants. The drafting process began in September 2006 and lasted almost two years. The US Forest Service Center for Urban Forest Research (CUFR) provided extensive technical expertise and led the two-year drafting process. On June 1, 2008, CUFR provided a draft version of the Urban Forestry Protocol to the Reserve. After June 1, 2008, the Reserve adapted the CUFR draft to fits its overarching policy framework, the result being this specific protocol now under 30-day public review.

During the two-year drafting period, several hundred people were involved in writing, reviewing, commenting on, and revising the Protocol. Four committees were active in the process (see list of participants below). The Steering Committee consisted of representatives from relevant agencies and key stakeholder groups such as utilities, nonprofit tree groups, and the professions of arboriculture and urban forestry. They provided high-level guidance from beginning to end. The Drafting Committee did the detailed work required to develop an outline, create case study examples, and compose the final draft for the Reserve. The Technical Review Committee consisted of subject-matter experts in the fields of urban forestry, carbon sequestration, energy conservation, bioenergy, and wood utilization. Members of this committee provided peer-reviews on the outline and the draft document. Approximately 70 members of the Stakeholder Committee also commented on the outline and draft document. An ad-hoc Utility Working Group discussed project activities most relevant to utilities. Colleagues of the U.S. Forest Service Center for Urban Forest Research (CUFR) collaborated on development and testing of the CUFR Tree Carbon Calculator. Broad participation and extensive outreach have resulted in widespread awareness of the Protocol.

In addition to the committees below, the following people from CUFR were closely involved in drafting the protocol: Elena Aguaron-Fuente, Paula Peper, James Simpson, and Sharon Yeh from the U.S. Forest Service Pacific Southwest Research Station and Cathy Bleier (CalFire, Drafting Committee Emeritus). The Utility Working Group was comprised of: Misha Sarkovich (SMUD), Greg San Martin, Pam Murray, Bob Bell, Lisa Randle (PG&E), Frank Schultz, John Mount (SoCal Edison), Jacqueline McRae (LADWP), Mike Daleo (SDG&E). Qingfu Xiao (UC Davis) provided information on remote sensing; and Ted Swiecki (Phytosphere) assisted with biomass equations.

Drafting committee

Glenn	Flamik	CalFire
Sam	Hitz	California Climate Action Registry
Mary	Klaas-Schultz	CalFire
Greg	McPherson	US Forest Service, PSW Res Stn, Center for Urban Forest Research
John	Nickerson	California Climate Action Registry
Michelle	Passero	The Nature Conservancy
Tim	Robards	CalFire
Emily	Russell-Roy	Pacific Forest Trust
Kelaine	Vargas	US Forest Service, PSW Res Stn, Center for Urban Forest Research
Laurie	Wayburn	Pacific Forest Trust
Doug	Wickizer	CalFire

Steering committee

Kathryn	Bickel	California Climate Action Registry
Glenn	Flamik	CalFire
Bruce	Goines	US Forest Service, Region 5
Sam	Hitz	California Climate Action Registry
Bailey	Hudson	Arborist
Mary	Klaas-Schultz	CalFire
Andy	Lipkis	TreePeople
Greg	McPherson	US Forest Service, PSW Res Stn, Center for Urban Forest Research
Mark	Nechodom	US Forest Service, Pacific Southwest Research Station
John	Nickerson	California Climate Action Registry
Jeanne	Panek	California Air Resources Board
Michelle	Passero	EcoSecurities
Tim	Robards	California Climate Action Registry
Emily	Russell-Roy	Pacific Forest Trust
Misha	Sarkovich	Sacramento Municipal Utility District
Klaus	Scott	California Air Resources Board
Val	Tiangco	California Energy Commission, Public Interest Energy Research
Kelaine	Vargas	US Forest Service, PSW Res Stn, Center for Urban Forest Research
Laurie	Wayburn	Pacific Forest Trust
Doug	Wickizer	CalFire

Technical advisory committee

Kamran	Abdollahi	Southern University
Rich	Birdsey	US Forest Service, Global Change
Ken	Decio	California Integrated Waste Mgmt Board
Pierre	duVair	California Energy Commission
Gordon	Heisler	US Forest Service, Syracuse
Ken	Holman	Community Forestry Coordinator, MN DNR, Forestry
David	Katz	Sacramento Tree Foundation
Gary	Klein	California Energy Commission
Jeff	Kline	US Forest Service, Pacific Northwest Research Station
Scott	Maco	Davey Resource Group
Doug	McCreary	UC Berkeley, Integrated Hardwood Range Management Program
Melissa	McHale	Arizona State University
Dave	Nowak	US Forest Service, Syracuse
Eric	Oldar	CalFire
Diane	Pataki	UC Irvine
Norm	Pillsbury	California Polytechnic State University, San Luis Obispo
Stephanie	Pincetl	US Forest Service, Pacific Southwest Research Station
Keith	Roberts	City of Sacramento
Neil	Sampson	The Sampson Group
Tom	Scott	UC Riverside, Integrated Hardwood Range Management Program
Sam	Sherrill	University of Cincinnati
Mark	Trexler	EcoSecurities Global Consulting Services
Andrea	Tuttle	UC Berkeley
Jude	Wait	Lomakatsi Restoration Project
Rob	Williams	California Biomass Collaborative/UC Davis

Stakeholder committee

James	Allen	James P. Allen and Assoc, Consulting Arborists
Curtis	Alling	EDAW, Inc.
Mike	Alonzo	Casey Trees
Manuel	Alvarado	Great Valley Center
Joe	Bates	Landscape Management, City of Vallejo
Robert	Beebe	University of La Verne
Edith	Ben-Hurin	TreePeople
Joe	Benassini	City of Sacramento, Urban Forestry
Melissa	Brandt	PG&E
Steve	Brink	California Forestry Association
Micah	Brosnan	PG&E
Doug	Brown	California Dept. of Transportation
Xantha	Bruso	PG&E
Lee	Butterfield	California State Parks
Rob	Cain	City of Davis
Keith	Cline	US Forest Service, Urban and Community Forestry
Phil	Cody	UC Berkeley
Larry	Costello	UC Coop Extension - Urban Horticulture
Mike	Daleo	San Diego Gas & Electric
Paula	Daniels	City of Los Angeles
Florence	Daviet	World Resources Institute
Rachel	Dinno	Trust for Public Lands
Eric	Douglas	California Tree Collaborative
Steve	Dugas	California State University Fullerton
Rose	Eperson	Western Chapter ISA
Alice	Ewen-Walker	Alliance for Community Trees
Richard	Farmer	Cal Poly Pomona
Herb	Fong	Stanford
Rebecca	Fotu	City of Morgan Hill
Leslie	Friedman Johnson	Conservation Strategy Group
Connie	Gallippi	Conservation Strategy Group
Melanie	Gentles	UC Davis
George	Gentry	Board of Forestry and Fire Protection, Executive Officer

Stakeholder committee

George	Gonzalez	Los Angeles Urban Forestry Program
John	Goodfellow	BioCompliance
Nancy	Griffiths	Amma Center of New Mexico
Jeff	Harris	Ellison, Schneider & Harris
Jay	Hart	Parks and Recreation Dept., City of Albuquerque, NM
Dudley	Hartel	USFS, Southern Center for Urban Forestry Research
Clay	Hinkle	CH2M Hill
Ron	Hostick	San Diego State University
Valerie	Huelsman	Alliance for Community Trees
Nancy	Hughes	California Urban Forest Council
Eric	Johnson	University of Southern California
Betony	Jones	Sierra Business Council
Patti	Keating	California State Parks
Kimberly	Klunich	US Environmental Protection Agency
Dan	Knapp	Los Angeles Conservation Corps
Nick	Kuhn	City of Albuquerque, NM, Parks and Recreation
Jerri	Lehaie	Society of Municipal Arborists
Jared	Liu	Alliance for Community Trees
Bill	Machado	Building Industry Association
Sandy	Macias	US Forest Service, Urban and Community Forestry
Gordon	Mann	Sacramento Tree Foundation
Ryan	McCaughey	CSU Fresno
Mark	McLoughlin	Stonebridge Properties
Jacqueline	McRae	Los Angeles Dept.of Water and Power, Trees for a Greener LA
Peter	Miller	Natural Resources Defense Council
Pam	Murray	PG&E
Sam	Oludunfe	University of California, San Diego
Martha	Ozonoff	California ReLeaf
Heath	Packard	Audubon Society
Robert	Parkhurst	PG&E
Cindy	Parsons	LADWP Environmental Services
Miguel	Perez-Gibson	Forest and Fish Conservation Caucus
Lisa	Randle	PG&E
David	Roger	Urban forestry consultant

Stakeholder committee		
Greg	San Martin	Climate Protection, PG&E
Daran	Santi	PG&E
Janet	Santos Cobb	California Oak Foundation
Mike	Schonherr	PG&E
Frank	Schultz	Southern California Edison
Mitch	Sears	City of Davis
Kemba	Shakur	Urban ReLeaf
Dan	Smith	Casey Trees
Carl	Somers	Trust for Public Lands
Guy	Stivers	Dudek Engineering and Environmental Consultants
Ray	Tretheway	Sacramento Tree Foundation
Ken	Trott	Woodland Tree Foundation
Andy	Trotter	West Coast Arborist
Richard	Williams	UC Santa Barbara
Scott	Wilson	Arborist
Deric	Wittenborn	Ellison, Schneider & Harris
Laura	Wyatt	Wisconsin Dept of Natural Resources