California Air Resources Board

Quantification Methodology

Department of Forestry & Fire Protection (CAL FIRE)
Urban and Community Forestry Program

California Climate Investments

FINAL
January 28, 2020

Table of Contents

List of Acronyms and Abbreviations

Acronym	Term
Btu	British thermal unit
C	carbon
CARB	California Air Resources Board
Diesel PM	diesel particulate matter
g	grams
gal	gallons
GGRF	Greenhouse Gas Reduction Fund
GHG	greenhouse gas
kg	kilograms
kg C	Kilograms of carbon
kWh	kilowatt hours
lb	pounds
lb CO2e	pounds of carbon dioxide equivalent
MMBtu	one million British thermal units
MT	metric ton
MT CO2e	metric tons of carbon dioxide equivalent
MT C	metric tons of carbon
MWh	megawatt hour
NOx	nitrous oxide
PM_{10}	particulate matter with a diameter less than 10 micrometers
$PM_{2.5}$	particulate matter with a diameter less than 2.5 micrometers
ROG	reactive organic gas
scf	standard cubic feet
short ton	common ton (US)
therm	one thousand British thermal units
UCF	Urban and Community Forestry

Section A. Introduction

California Climate Investments is a statewide initiative that puts billions of Cap-and-Trade dollars to work facilitating greenhouse gas (GHG) emission reductions; strengthening the economy; improving public health and the environment; and providing benefits to residents of disadvantaged communities, low-income communities, and low-income households, collectively referred to as "priority populations." Where applicable and to the extent feasible, California Climate Investments must maximize economic, environmental, and public health co-benefits to the State.

The California Air Resources Board (CARB) is responsible for providing guidance on estimating the net GHG benefit and co-benefits from projects receiving monies from the Greenhouse Gas Reduction Fund (GGRF). This guidance includes quantification methodologies, co-benefit assessment methodologies, and benefits calculator tools. CARB develops these methodologies and tools based on the project activities eligible for funding by each administering agency, as reflected in the program expenditure records available at: www.arb.ca.gov/cci-expenditurerecords.

For the California Department of Forestry & Fire Protection (CAL FIRE) Urban and Community Forestry (UCF) Program, CARB staff developed this UCF Quantification Methodology to provide guidance for estimating the net GHG benefit and selected co-benefits of each proposed project activity. This methodology uses calculations to estimate carbon sequestration in planted trees, GHG emission reductions from the effects of tree shade on building energy use, carbon stored long-term in wood products, avoided GHG emissions from the displacement of fossil fuels resulting from utilizing biomass for electricity generation, avoided GHG emissions from preventing the landfilling of biomass, and GHG emissions associated with the implementation of UCF projects.

The UCF Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with a project example, and outlines documentation requirements. Projects will report the total project GHG benefit and co-benefits estimated using the UCF Benefits Calculator Tool, as well as the total project GHG benefit per dollar of GGRF funds requested. The UCF Benefits Calculator Tool is available for download at: http://www.arb.ca.gov/cci-resources.

Using many of the same inputs required to estimate net GHG benefit, the UCF Benefits Calculator Tool estimates the following co-benefits and key variables from UCF projects: trees planted (quantity of trees), fossil fuel based energy use reductions (kWh and therms), renewable energy generation (kWh), energy cost savings (dollars), water savings (gallons and acre feet per year), and select criteria and toxic air pollutant emissions (pounds) – including reactive organic gases (ROG), nitrogen oxide (NOx), and fine particulate matter less than 2.5 micrometers ($PM_{2.5}$). Key variables are project characteristics that contribute to a project's net GHG benefit and signal an additional benefit (e.g., energy use reductions, renewable energy generation, and number of trees planted). Additional co-benefits for which CARB assessment methodologies were not incorporated into the UCF Benefits Calculator Tool may also be applicable to the project. Applicants should consult the UCF guidelines, solicitation materials, and agreements to ensure they are meeting UCF Program requirements. All CARB co-benefit assessment methodologies are available at: www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and CAL FIRE developed this Quantification Methodology consistent with the guiding principles of California Climate Investments, including ensuring transparency and accountability.[1] CARB and CAL FIRE developed this UCF Quantification Methodology to be used to estimate the outcomes of proposed projects, inform project selection, and track results of funded projects. The implementing principles ensure that the methodology would:

- Apply at the project-level;
- Provide uniform methods to be applied statewide, and be accessible by all applicants;
- Use existing and proven tools and methods;
- Use project-level data, where available and appropriate; and
- Result in net GHG benefit estimates that are conservative and supported by empirical literature.

CARB assessed peer-reviewed literature and tools and consulted with experts, as needed, to determine methods appropriate for the UCF project activities. CARB also consulted with CAL FIRE to determine project-level inputs available. The methods were developed to provide estimates that are as accurate as possible with data readily available at the project level. CARB released the Draft UCF Quantification Methodology and Draft UCF Benefits Calculator Tool for public comment in December 2019. This Final UCF Quantification Methodology and accompanying UCF Benefits Calculator Tool have been updated to address public comments, where appropriate, and for consistency with updates to the UCF Program Guidelines.

[1] California Air Resources Board. (2018). *CCI Funding Guidelines for Administrating Agencies.* www.arb.ca.gov/cci-fundingguidelines

In addition, the University of California, Berkeley, in collaboration with CARB, developed assessment methodologies for a variety of co-benefits such as providing cost savings, providing water savings, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted at: www.arb.ca.gov/cci-cobenefits.

Tools

The UCF Benefits Calculator Tool relies on project-specific outputs from one of the two U.S. Department of Agriculture Forest Service (USFS) urban tree carbon accounting tools:

The USFS i-Tree Planting web-based tool provides quantitative data for an individual or population of trees planted as part of the project, including the amount of carbon stored, the estimated effects of tree shade on building energy use, the dry weight of aboveground biomass, and rainfall interception based on project characteristics such as the climate zone, tree species, tree age, tree diameter at breast height (DBH), and tree location relative to a building. i-Tree Planting can be accessed at: https://planting.itreetools.org/. A description about the tool can be accessed at: https://planting.itreetools.org/help/.

The USFS i-Tree Streets software tool provides quantitative data for an entire population of urban trees planted as part of a project, including the amount of carbon stored, the estimated effects of tree shade on building energy use, and rainfall interception based on project characteristics such as the climate zone, tree species, and tree DBH. i-Tree Streets can be downloaded from: https://www.itreetools.org/. A user manual for i-Tree Streets is available from: https://www.itreetools.org/resources/manuals/Streets_Manual_v5.pdf.

The i-Tree Planting and i-Tree Streets tools are used statewide, subject to regular updates to incorporate new information, free of charge, and publicly available to anyone with internet access. Applicants can choose which of these tools to use to estimate the GHG benefit of tree planting, but only i-Tree Planting provides an estimate of tree biomass, so applicants must use this tool to estimate the GHG benefit of biomass utilization.

User Tip:

Step-by-step instructions included in previous quantification methodology documents are now included in a user guide, which includes a project example.

The UCF Benefits Calculator Tool also includes water savings co-benefit calculations that require the use of the Department of Water Resources (DWR) Water Budget Calculator for New and Rehabilitated Residential/Non-Residential Landscapes[2] and the University of California Division of Agriculture and Natural Resources (UCANR) Water Use Classification of Landscape Species (WUCOLS) IV online database.[3] In order to estimate water savings resulting from the project activities, refer to CARB's Co-benefit Assessment Methodology for Water Savings, available at: https://www.arb.ca.gov/cc/capandtrade/auctionproceeds/final_water_am.pdf, which includes an urban landscaping project example in Appendix C.

In addition to the tools above, the UCF Benefits Calculator Tool relies on CARB-developed emission factors. CARB has established a single repository for emission factors used in CARB benefits calculator tools, referred to as the California Climate Investments Quantification Methodology Emission Factor Database (Database), available at: http://www.arb.ca.gov/cci-resources. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

Applicants must use the UCF Benefits Calculator Tool to estimate the net GHG benefit and co-benefits of the proposed project. The UCF Benefits Calculator Tool can be downloaded from: http://www.arb.ca.gov/cci-resources.

Updates

CARB staff periodically review each quantification methodology and benefits calculator tool to evaluate their effectiveness and update methodologies to make them more robust, user-friendly, and appropriate to the projects being quantified. CARB updated the UCF Quantification Methodology from the previous version[4] to enhance the analysis and provide additional clarity.

---

[2] Department of Water Resources (2017). *Water Budget Calculator for New and Rehabilitated Residential/Non-Residential Landscapes*. http://water.ca.gov/wateruseefficiency/landscapeordinance/docs/BetaWaterBudgetNonResidentialV130.xlsm

[3] University of California Division of Agriculture and Natural Resources. (2019). *Water Use Classification of Landscape Species (WUCOLS) IV online database*. http://ucanr.edu/sites/WUCOLS/Plant_Search/

[4] California Air Resources Board. (2018). *Quantification Methodology for the CAL FIRE Urban and Community Forestry Program, Greenhouse Gas Reduction Fund FY17-18*. https://ww3.arb.ca.gov/cc/capandtrade/auctionproceeds/calfire_ucf_finalqm_version2_020419.pdf

The changes in this update include:

- Updates to the step-by-step user guide with a project example;
- Updates to the emission factors used to estimate energy saved or displaced and associated cost savings and air pollutant emission reductions.
- Updates to the UCF Benefits Calculator Tool to categorize air pollutant emission reductions as local (tree interception of air pollutant deposition and natural gas emissions from winter tree shade) or remote (avoided grid electricity use and avoided landfill emissions)
- Updates to the UCF Benefits Calculator Tool to correct water savings estimate as irrigation savings only. The previous version of the tool incorrectly summed rainfall interception, stormwater runoff, and irrigation savings as total water savings.

Section B. Methods

The following section provides details on the methods supporting emission reduction estimates in the UCF Benefits Calculator Tool.

Urban and Community Forestry Project Activities

CAL FIRE developed three project activities that meet the objectives of the UCF Program and for which there are methods to quantify a net GHG benefit[5] Other project features may be eligible for funding under the UCF Program; however, each project requesting GGRF funding must include at least one of the following:

- Tree planting; or
- Biomass utilization for wood products; or
- Biomass utilization for electricity generation.

General Approach

Methods used in the UCF Benefits Calculator Tool for estimating the net GHG benefit and air pollutant emission co-benefits by activity type are provided in this section. The Database Documentation explains how emission factors used in CARB benefits calculator tools are developed and updated.

---

[5] Department of Forestry & Fire Protection. (2019). Urban and Community Forestry Grant Programs. http://www.fire.ca.gov/resource_mgt/resource_mgt_urbanforestry_grants#

These methods account for carbon storage in planted trees, energy savings from the benefits of tree shade, carbon stored long-term in wood products, avoided GHG emissions from the generation of electricity from biomass, avoided GHG landfill emissions from the utilization of biomass, and the GHG emissions associated with the implementation of UCF projects. In general, the net GHG benefit is estimated in the UCF Benefits Calculator Tool using the approaches in Table 1. The UCF Benefits Calculator Tool also estimates air pollutant emission co-benefits and key variables using many of the same inputs used to estimate the net GHG benefit.

Table 1. General Approach to Quantification by Project Activity

Tree Planting
Net GHG benefit = carbon storage in planted trees – carbon in planted trees not assumed to survive[6] *+ GHG reductions from energy savings from shade*[7] *– GHG emissions from tree planting and maintenance*
Biomass Utilization for Wood Products
Net GHG Benefit = carbon stored long-term in wood products + avoided GHG emissions from landfills – GHG emissions from mill
Biomass Utilization for Electricity Generation
Net GHG Benefit = avoided GHG emissions from displaced fossil fuel energy + avoided GHG emissions from landfills – GHG emissions from biomass facility

User Tip:

Due to the difference in outputs from the two urban tree accounting tools available for use, some equations are tool-specific, as indicated in the next section.

---

[6] This methodology applies a 3% annual tree mortality rate to the years after the period of establishment care (including replacement) provided by the project through year 10, at which time tree mortality is substantially reduced. This assumption is based on USFS publications and personal communication with John Melvin, State Urban Forester, CAL FIRE (April 19, 2016).

[7] Some tree planting sites may not provide shade to buildings and will therefore not result in building energy savings. If there are no trees that provide tree shade to conditioned buildings in the proposed project, this variable may be set to 0. If only a subset of trees will provide shade, see the step-by-step user guide for additional details about how to apply the third party tools, i-Tree Planting and i-Tree Streets.

A. GHG Benefit from Carbon Stored in Trees Planted by the Urban and Community Forestry Project

The GHG benefit from carbon stored in trees planted by the project is calculated as the sum of carbon stored in individual trees 40 years after project start. A 3% annual tree mortality rate[8] is included for the years after the period of establishment care (including replacement) provided by the project through year 10.[9] Equation 1 determines the GHG benefit from carbon stored in live project trees at the end of the project if the applicant used i-Tree Planting. Equation 2 is used if the applicant used i-Tree Streets.

Equation 1: GHG Benefit of Carbon Stored in Live Project Trees *(i-Tree Planting)*

$$GHG_{CSC} = \frac{\sum_i C_{ITP,i} \times (1-0.03)^{10-YC}}{2{,}204.62}$$

Where,			Units
GHG_{CSC}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Planting	MT CO_2e
$C_{ITP,i}$	=	Carbon stored in each group of project trees (i), over the 40 year quantification period (from i-Tree Planting)	lb CO_2e
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years
i	=	Project tree planted	
2,204.62	=	Conversion factor from lb to MT	lb/MT

---

[8] Roman, Lara. (2014). How many trees are enough? Tree death and the urban canopy. *Scenario Journal*. http://www.fs.fed.us/nrs/pubs/jrnl/2014/nrs_2014_roman_001.pdf
United States Department of Agriculture Forest Service. *i-Tree ECO Guide to Using the Forecast Model*. http://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6Guide_UsingForecast.pdf
United States Department of Energy Information Administration. (1998). *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings*. http://www3.epa.gov/climatechange/Downloads/method-calculating-carbon-sequestration-trees-urban-and-suburban-settings.pdf

[9] Establishment and replacement care reduces the risk of mortality of trees planted by the project. Because this methodology applies an increased mortality rate in the first ten years after planting when trees are most at risk, the maximum value for years of establishment care in Equations 1-4 is 9 years to limit the tree mortality rate to 3%.

Equation 2: GHG Benefit of Carbon Stored in Live Project Trees *(i-Tree Streets)*

$$GHG_{CSI} = \frac{\sum_i C_{ITS} \times (1-0.03)^{10-YC}}{2{,}204.62}$$

Where,			Units
GHG_{CSI}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Streets	MT CO_2e
C_{ITS}	=	Total carbon stored in population of project trees 40 years after project start (from i-Tree Streets)	lb CO_2e
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years
2,204.62	=	Conversion factor from lb to MT	lb/MT

B. GHG Benefit from Energy Savings as a Result of Strategically Planting Trees to Shade Buildings

The GHG benefit from energy savings is calculated as the total annual energy savings from individual trees planted strategically to shade buildings (i.e., planted within 60 feet) during the 40 year quantification period, taking tree mortality into account. Equation 3 determines the GHG emission reductions from energy savings throughout the quantification period of the project if the applicant used i-Tree Planting.

Equation 4 is used to determine the GHG emission reductions from energy savings throughout the quantification period of the project if the applicant used i-Tree Streets. Because young trees do not provide significant shade during the first 20 years of life and the energy savings value from i-Tree Streets is an estimate of the annual savings when the tree provides the greatest shade, the annual value is multiplied by the remaining 20 years to estimate the GHG emission benefit over 40 years.[10]

Equation 3: GHG Benefit from Energy Savings *(i-Tree Planting)*

$$GHG_{ESC} = \left(\frac{\sum_i ER_{ITP,i}}{1,000} \times EF_{ELEC} + \sum_i NG_{ITP,i} \times 10 \times EF_{NG}\right) \times (1 - 0.03)^{10-YC}$$

Where,

			Units
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting	MT CO_2e
$ER_{ITP,i}$	=	Total electricity reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)	kWh
EF_{ELEC}	=	GHG emission factor for electricity	MT CO_2e/ MWh
1,000	=	Conversion factor from kWh to MWh	kWh/MWh
$NG_{ITP,i}$	=	Total annual natural gas reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)	MMBtu
10	=	Conversion factor from MMBtu to therms	therm/ MMBtu
EF_{NG}	=	GHG emission factor for natural gas	MT CO_2e/ therm
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years
i	=	Group of project trees planted	

[10] Greg McPherson, Research Forester, US Forest Service (April 25, 2016) personal communication.

Equation 4: GHG Benefit from Energy Savings *(i-Tree Streets)*

$$GHG_{ESI} = (ER_{ITS} \times EF_{ELEC} + NG_{ITS} \times EF_{NG}) \times (1 - 0.03)^{10-YC} \times Shade\ \% \times 20$$

Where,			Units
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets	MT CO_2e
ER_{ITS}	=	Total annual electricity reductions from population of project trees 40 years after project start (from i-Tree Streets)	MWh
EF_{ELEC}	=	GHG emission factor for electricity	MT CO_2e/ MWh
NG_{ITS}	=	Total annual natural gas reductions from population of project trees 40 years after project start (from i-Tree Streets)	therms
EF_{NG}	=	GHG emission factor for natural gas	MT CO_2e/ therm
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years
Shade %	=	Percent of trees planted to shade buildings (i.e., within 60 feet)	%
20	=	Years adjusted for annual energy savings output at year 40	years

C. GHG Emissions from Project Implementation

Tree planting projects must account for GHG emissions from tree planting, maintenance, and other tree-related activities. The GHG emissions from implementation of tree planting projects are calculated by deducting 5%[11] of the annual reductions obtained through carbon storage and avoided emissions from energy savings. Equation 5 is used to determine the GHG emissions from implementation of tree planting projects.

Equation 5: GHG Emissions from Tree Planting Project Implementation

$$GHG_{PI} = (GHG_{CSC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI}) \times EF_{IMP}$$

Where,			Units
GHG_{PI}	=	GHG emissions from tree planting	MT CO_2e
GHG_{CSC}	=	GHG benefit from carbon stored in live project trees estimated using i-Tree Planting (from Equation 1)	MT CO_2e
GHG_{CSI}	=	GHG benefit from carbon stored in live project trees estimated using i-Tree Streets (from Equation 2)	MT CO_2e
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3)	MT CO_2e
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4)	MT CO_2e
EF_{IMP}	=	Emission factor for project emissions	

The process and transportation emissions associated with tree removal in an urban wood and biomass utilization project are excluded from this quantification methodology because the trees to be utilized are trees that would be removed and transported to a landfill without the project. Process emissions at a mill or biomass facility are factored into the emission reduction factor for these activities.

[11] U.S. Department of Agriculture Forest Service, Tree Guides (multiple publications). https://www.fs.fed.us/psw/topics/urban_forestry/products/tree_guides.shtml

D. Air Pollutant Co-Benefit from Trees Planted by the Project

The air pollutant emissions co-benefit from trees planted by the project is calculated as the sum of air pollutant emissions removed from the atmosphere by individual trees during the 40 year quantification period, accounting for a 3% annual tree mortality rate for the years after the period of establishment care (including replacement) provided by the project through year 10. Equations 6 and 7 are used to determine the air pollutant emission co-benefits from live project trees at the end of the project if the applicant used i-Tree Planting or i-Tree Streets.

Equation 6: $PM_{2.5}$ Emissions Co-benefit from Tree Absorption

$$PM_{2.5,TA} = \left((ER_{PM,ITP} \times 0.28) + (ER_{PM,ITS} \times 20 \times 0.28) \right) \times (1 - 0.03)^{10-YC}$$

Where,			<u>Units</u>
$PM_{2.5,TA}$	=	$PM_{2.5}$ benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets	lb
$ER_{PM,ITP}$	=	Total $PM_{2.5}$ savings over the 40 year quantification period calculated from i-Tree Planting	lb
$ER_{PM,ITS}$	=	Annual PM_{10} savings 40 years after project start calculated from i-Tree Streets	lb
20	=	Years adjusted for annual savings output at year 40	years
0.28	=	Conversion from PM_{10} to $PM_{2.5}$	$PM_{2.5}/PM_{10}$
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 7: NO_x Emissions Co-benefit from Tree Absorption

$$NO_{x,TA} = \left(ER_{NOx,ITP} + (ER_{NOx,ITS} \times 20)\right) \times (1 - 0.03)^{10-YC}$$

Where,			Units
$NO_{x,TA}$	=	NO_x benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets	lb
$ER_{NOx,ITP}$	=	Total NO_x savings over the 40 year quantification period calculated from i-Tree Planting	lb
$ER_{NOx,ITS}$	=	Annual NO_x savings 40 years after project start calculated from i-Tree Streets	lb
20	=	Years adjusted for annual savings output at year 40	years
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

E. Air Pollutant Co-benefit from Energy Savings as a Result of Strategically Planting Trees to Shade Buildings

Equations 8 through 10 are used to determine the air pollutant emission co-benefits from energy savings throughout the quantification period of the project if the applicant used i-Tree Planting or i-Tree Streets.

Equation 8: $PM_{2.5}$ Emissions Co-benefit from Energy Savings

$$PM_{2.5.ES} = \Big(\big(ER_{ITP} + (ER_{ITS} \times Shade\,\% \times 20 \times 1{,}000)\big) \times PM_{ELEC} + (NG_{ITP} + (NG_{ITS} \times Shade\,\% \times 0.1 \times 20)) \times PM_{NG}\Big) \times (1 - 0.03)^{10-YC}$$

Where,			Units
$PM_{2.5,ES}$	=	$PM_{2.5}$ benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings 40 years after project start calculated from i-Tree Streets	MWh
Shade %	=	The percent of the trees planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
PM_{ELEC}	=	$PM_{2.5}$ emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therm
PM_{NG}	=	$PM_{2.5}$ emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 9: NO_x Emissions Co-benefit from Energy Savings

$$NO_{x,ES} = \Big(\big(ER_{ITP} + (ER_{ITS} \times Shade\,\% \times 20 \times 1{,}000)\big) \times NOX_{ELEC} + (NG_{ITP} + (NG_{ITS} \times Shade\,\% \times\ 0.1 \times 20)) \times NOX_{NG}\Big) \times (1 - 0.03)^{10-YC}$$

Where,			Units
$NO_{x,ES}$	=	NO_x benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings 40 years after project start calculated from i-Tree Streets	MWh
Shade %	=	The percent of the trees planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
NOX_{ELEC}	=	NO_x emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therm
NOX_{NG}	=	NO_x emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

Equation 10: ROG Emissions Co-benefit from Energy Savings

$$ROG_{ES} = \Big(\big(ER_{ITP} + (ER_{ITS} \times Shade\ \% \times 20 \times 1{,}000)\big) \times ROG_{ELEC} + (NG_{ITP} + (NG_{ITS} \times Shade\ \% \times\ 0.1 \times 20)) \times ROG_{NG}\Big) \times (1 - 0.03)^{10-YC}$$

Where,			Units
ROG_{ES}	=	ROG benefit from energy savings estimated using i-Tree Planting and i-Tree Streets	lb
ER_{ITP}	=	Total energy savings over the 40 year quantification period calculated from i-Tree Planting	kWh
ER_{ITS}	=	Annual energy savings calculated from i-Tree Streets	MWh
Shade %	=	The percent of the trees planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets	%
20	=	Years adjusted for annual energy savings output at year 40	years
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
ROG_{ELEC}	=	ROG emission factor for electricity	lb/kWh
NG_{ITP}	=	Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting	MMBtu
NG_{ITS}	=	Annual natural gas savings 40 years after project start calculated from i-Tree Streets	therms
0.1	=	Conversion from therms to MMBtu	MMBtu/therm
ROG_{NG}	=	ROG emission factor for natural gas	lb/MMBtu
0.03	=	Mortality rate (3% annual)	
10	=	Years after planting with greatest risk for mortality	years
YC	=	Years of establishment and replacement care provided by project (the maximum value for the purposes of this equation is 9 years; enter 9 if the project provides establishment and replacement care for a longer period of time)	years

F. GHG Benefit of Carbon Stored Long-Term in Wood Products

The GHG benefit from carbon stored long-term in wood products is calculated based on the sum of the aboveground biomass utilized for wood products over a 10 year period, mill efficiency,[12] and the carbon storage factor of the wood products generated. Projects may use the actual efficiency from the mill where trees are delivered, supported with documentation, or the appropriate default mill efficiency based on the type of wood provided in Table 2. If trees are delivered to more than one mill with different efficiencies, applicants may provide a weighted mill efficiency. Equation 11 is used to determine the amount of carbon transferred to wood products.

Equation 11: Carbon Transferred to Wood Products

$$C_{WP} = \frac{\sum_i \left(AGB_{ITP,WP,i} \times 907.18474\right) \times 0.5}{1{,}000} \times ME$$

Where,			Units
C_{WP}	=	Carbon transferred to wood products	MT C
$AGB_{ITP,WP,i}$	=	Aboveground biomass of each group of project trees (i) at time of removal to be utilized for wood products (biomass weight from i-Tree Planting)	short ton
907.18474	=	Conversion factor from short ton to kg	kg/short ton
i	=	Removed project tree to be utilized for wood products	
0.5	=	Conversion factor from wood to carbon	kg C/kg wood
1,000	=	Conversion factor from kg to MT	kg/MT
ME	=	Mill efficiency	%

Table 2. Default Mill Efficiency

Hardwood	Softwood
56.8%	67.5%

After determining the carbon transferred to wood products, the amount of carbon stored long term in wood products must be calculated. To do this, determine the percentage of removed biomass that will go into each wood product class category. If

[12] Mill efficiencies represent the portion of logs that are converted to wood products, or the percentage of the total carbon delivered to a mill that is transferred into wood products. For accounting purposes, the remainder of the carbon is considered to be immediately emitted to the atmosphere.

not available from the mill that wood is delivered to, assume that 100% of the biomass goes into "miscellaneous products." Default carbon storage factors, the percent of carbon transferred to wood products that remains stored long-term, are provided. Equation 12 is used to determine the GHG benefit of utilizing biomass for wood products.

Equation 12: GHG Benefit of Carbon Stored in Wood Products

$$GHG_{WP} = [(C_{WP} \times SL \times 0.463) + (C_{WP} \times HL \times 0.250) + (C_{WP} \times SP \times 0.484) + (C_{WP} \times OS \times 0.582) + (C_{WP} \times NP \times 0.380) + (C_{WP} \times P \times 0.058) + (C_{WP} \times MP \times 0.176)] \times 3.67$$

Where,			Units
GHG_{WP}	=	GHG benefit of carbon stored in wood products	MT CO_2e
C_{WP}	=	Carbon transferred to wood products (from Equation 11)	MT C
SL	=	Percentage of biomass that will go into softwood lumber	%
0.463	=	Carbon storage factor for softwood lumber	
HL	=	Percentage of biomass that will go into hardwood lumber	%
0.250	=	Carbon storage factor for hardwood lumber	
SP	=	Percentage of biomass that will go into softwood plywood	%
0.484	=	Carbon storage factor for softwood plywood	
OS	=	Percentage of biomass that will go into oriented strand board	%
0.582	=	Carbon storage factor for oriented strand board	
NP	=	Percentage of biomass that will go into nonstructural panels	%
0.380	=	Carbon storage factor for nonstructural panels	
P	=	Percentage of biomass that will go into paper	%
0.058	=	Carbon storage factor for paper	
MP	=	Percentage of biomass that will go into miscellaneous products	%
0.176	=	Carbon storage factor for miscellaneous products	
3.67	=	Conversion factor from C to CO_2e	CO_2e/C

G. Air Pollutant Co-benefit from Carbon Stored Long-Term in Wood Products

The air pollutant co-benefit from carbon stored long-term in wood products is calculated based on the avoided flare emissions of sending the material to a landfill for disposal. Equations 13 through 15 are used to determine the co-pollutant emission reductions.

Equation 13: $PM_{2.5}$ Emissions Co-benefit from Carbon Storage in Wood Products

$$PM_{2.5,WP} = AGB_{ITP,WP} \times \frac{PM_{FLARE}}{0.52}$$

Where,			Units
$PM_{2.5,WP}$	=	$PM_{2.5}$ benefit from wood products	lb
$AGB_{ITP,WP}$	=	Total biomass calculated from i-Tree Planting	short tons
PM_{FLARE}	=	$PM_{2.5}$ flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton

Equation 14: NO_x Emissions Co-benefit from Carbon Storage in Wood Products

$$NO_{x,WP} = AGB_{ITP,WP} \times \frac{NOX_{FLARE}}{0.52}$$

Where,			Units
$NO_{x,WP}$	=	NO_x benefit from wood products	lb
$AGB_{ITP,WP}$	=	Total biomass calculated from i-Tree Planting	short tons
NOX_{FLARE}	=	NO_x flare combustion emission factor	lb/wet short ton of green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton

Equation 15: ROG Emissions Co-benefit from Carbon Storage in Wood Products

$$ROG_{,WP} = AGB_{ITP,WP} \times \frac{ROG_{FLARE}}{0.52}$$

Where,			Units
$ROG_{,WP}$	=	ROG benefit from wood products	lb
$AGB_{ITP,WP}$	=	Total biomass calculated from i-Tree Planting	short tons
ROG_{FLARE}	=	ROG flare combustion emission factor	lb/wet short ton of green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton

H. GHG Benefit of Utilizing Biomass for Electricity Generation

The GHG benefit from utilizing biomass for electricity generation is calculated as the sum of the aboveground biomass utilized for electricity generation via combustion and gasification over a 10 year period multiplied by process-specific emission reduction factors. Equation 16 is used to determine the avoided GHG emissions resulting from utilizing biomass for electricity generation.

Equation 16: GHG Benefit from Utilizing Biomass for Electricity Generation

$$GHG_{EG} = \sum_{i} (AGB_{ITP,EC,i}) \times GHG_{COMBUST} + \sum_{i} (AGB_{ITP,EG,i}) \times GHG_{GAS}$$

Where,

			Units
GHG_{EG}	=	GHG benefit from utilizing biomass for electricity generation	MT CO_2e
$AGB_{ITP,EC,i}$	=	Aboveground biomass of each group of project trees (i) at time of removal to be utilized for electricity generation via combustion (biomass weight from i-Tree Planting)	short ton
$GHG_{COMBUST}$	=	Emission reduction factor for combustion	MT CO_2e/ ton of biomass
$AGB_{ITP,EG,i}$	=	Aboveground biomass of each group of project trees (i) at time of removal to be utilized for electricity generation via gasification (biomass weight from i-Tree Planting)	short ton
GHG_{GAS}	=	Emission reduction factor for gasification	MT CO_2e/ ton of biomass
i	=	Removed group of project trees to be utilized for electricity generation	

I. Air Pollutant Co-benefit from Utilizing Biomass for Electricity Generation from Combustion

The air pollutant co-benefit from combustion of biomass for electricity generation is calculated as the sum of the avoided grid electricity production and avoided flare emissions less the onsite emissions to combust biomass for electricity production. Equations 17 through 19 are used to determine the avoided co-pollutant emissions resulting from combustion of biomass for electricity generation.

Equation 17: $PM_{2.5}$ Emissions Co-benefit from Biomass Electricity Generation via Combustion

$$PM_{2.5,\,EC} = \left(AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times PM_{ELEC}\right) + \left(AGB_{ITP,EC} \times \frac{PM_{FLARE}}{0.52}\right) - \left(AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times PM_{COMBUST} \times 0.66\right)$$

Where,

			Units
$PM_{2.5,EC}$	=	$PM_{2.5}$ benefit from biomass combustion	lb
$AGB_{ITP,EC}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion from MWh to kWh	kWh/MWh
PM_{ELEC}	=	$PM_{2.5}$ electricity emission factor	lb/kWh
PM_{FLARE}	=	$PM_{2.5}$ flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
$PM_{COMBUST}$	=	PM biomass combustion factor	lb/kWh
0.66	=	Conversion from PM to $PM_{2.5}$	

Equation 18: NO_x Emissions Co-benefit from Biomass Electricity Generation via Combustion

$$NO_{x,\,EC} = \left(AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times NOX_{ELEC}\right) + \left(AGB_{ITP,EC} \times \frac{NOX_{FLARE}}{0.52}\right) - \left(AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times NOX_{COMBUST}\right)$$

Where,

			Units
$NO_{x,EC}$	=	NO_x benefit from biomass combustion	lb
$AGB_{ITP,EC}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion from MWh to kWh	kWh/MWh
NOX_{ELEC}	=	NO_x electricity emission factor	lb/kWh
NOX_{FLARE}	=	NO_x flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
$NOX_{COMBUST}$	=	NO_x biomass combustion factor	lb/kWh

Equation 19: ROG Emissions Co-benefit from Biomass Electricity Generation via Combustion

$$ROG_{EC} = (AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times ROG_{ELEC}) + \left(AGB_{ITP,EC} \times \frac{ROG_{FLARE}}{0.52}\right) - (AGB_{ITP,EC} \times 0.9 \times 1{,}000 \times ROG_{COMBUST})$$

Where,			Units
ROG_{EC}	=	ROG benefit from biomass combustion	lb
$AGB_{ITP,EC}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion from MWh to kWh	kWh/MWh
ROG_{ELEC}	=	ROG electricity emission factor	lb/kWh
ROG_{FLARE}	=	ROG flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
$ROG_{COMBUST}$	=	ROG biomass combustion factor	lb/kWh

J. Air Pollutant Co-benefit from Utilizing Biomass for Electricity Generation from Gasification

The air pollutant co-benefit from gasification of biomass for electricity generation is calculated as the sum of the avoided grid electricity production and avoided flare emissions less the onsite emissions from biomass gasification for electricity production. Equations 20 through 22 are used to determine the avoided co-pollutant emissions resulting from gasification of biomass for electricity generation.

Equation 20: $PM_{2.5}$ Emissions Co-benefit from Biomass Electricity Generation via Gasification

$$PM_{2.5,EG} = (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times PM_{ELEC}) + \left(AGB_{ITP,EG} \times \frac{PM_{FLARE}}{0.52}\right) - (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times PM_{GAS} \times 0.66)$$

Where,			Units
$PM_{2.5,EG}$	=	$PM_{2.5}$ benefit from biomass gasification	lb
$AGB_{ITP,EG}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion factor from MWh to kWh	kWh/MWh
PM_{ELEC}	=	$PM_{2.5}$ electricity emission factor	lb/kWh
PM_{FLARE}	=	$PM_{2.5}$ flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
PM_{GAS}	=	PM biomass gasification factor	lb/kWh
0.66	=	Conversion from PM to $PM_{2.5}$	

Equation 21: NO_x Emissions Co-benefit from Biomass Electricity Generation via Gasification

$$NO_{x,EG} = (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times NOX_{ELEC}) + \left(AGB_{ITP,EG} \times \frac{NOX_{FLARE}}{0.52}\right) - (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times NOX_{GAS})$$

Where,			Units
$NO_{x,EG}$	=	NO_x benefit from biomass gasification	lb
$AGB_{ITP,EG}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion from MWh to kWh	kWh/MWh
NOX_{ELEC}	=	NO_x electricity emission factor	lb/kWh
NOX_{FLARE}	=	NO_x flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
NOX_{GAS}	=	NO_x biomass gasification factor	lb/kWh

Equation 22: ROG Emissions Co-benefit from Biomass Electricity Generation via Gasification

$$ROG_{EG} = (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times ROG_{ELEC}) + \left(AGB_{ITP,EG} \times \frac{ROG_{FLARE}}{0.52}\right) - (AGB_{ITP,EG} \times 0.9 \times 1{,}000 \times ROG_{GAS})$$

Where,			Units
ROG_{EG}	=	ROG benefit from biomass gasification	lb
$AGB_{ITP,EG}$	=	Total biomass calculated from i-Tree Planting	short tons
0.9	=	MWh per ton of biomass waste	MWh/ton of biomass
1,000	=	Conversion from MWh to kWh	kWh/MWh
ROG_{ELEC}	=	ROG electricity emission factor	lb/kWh
ROG_{FLARE}	=	ROG flare combustion emission factor	lb/wet short ton green waste
0.52	=	Average dry weight percentage for tree biomass	dry ton/wet ton
ROG_{GAS}	=	ROG biomass gasification factor	lb/kWh

K. GHG Benefit of Preventing the Landfilling of Biomass

The avoided GHG emissions from preventing the landfilling of biomass and instead utilizing biomass for wood products or electricity generation is calculated as the sum of the biomass diverted from landfills over a 10 year period multiplied by an emission factor for green waste. Equation 23 is used to determine the avoided GHG emissions from preventing biomass from entering landfills.

Equation 23: GHG Benefit from Preventing the Landfilling of Biomass

$$GHG_L = \left(\sum_i (AGB_{ITP,WP,i}) + \sum_i (AGB_{ITP,EC,i}) + \sum_i (AGB_{ITP,EG,i})\right) \times \frac{GHG_{LANDFILL}}{0.52}$$

Where,			<u>Units</u>
GHG_L	=	GHG benefit from preventing the landfilling of biomass	MT CO_2e
$AGB_{ITP,WP,i}$	=	Aboveground biomass of project tree (i) at time of removal to be utilized for wood products (weight from i-Tree Planting)	short ton
$AGB_{ITP,EC,i}$	=	Aboveground biomass of project tree (i) at time of removal to be utilized for electricity generation via combustion (weight from i-Tree Planting)	short ton
$AGB_{ITP,EG,i}$	=	Aboveground biomass of project tree (i) at time of removal to be utilized for electricity generation via gasification (weight from i-Tree Planting)	short ton
i	=	Removed group of project trees to be utilized	
$GHG_{LANDFILL}$	=	Avoided landfill emission reduction factor	MT CO_2e/ wet short ton
0.52	=	Average dry weight percentage for tree biomass	dry ton/ wet ton

L. Net GHG Benefit

The net GHG benefit from any project is the sum of the carbon stored in planted trees, emission reductions from energy savings, carbon stored long-term in wood products, and avoided GHG emissions from utilizing biomass for energy generation of biomass energy, less the GHG emissions associated with the implementation of the project. Equation 24 is used to determine the net GHG benefit from urban and community forest projects.

Equation 24: Net GHG Benefit

$$GHG = (GHG_{CSC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI} + GHG_{WP} + GHG_{EG} + GHG_{L}) - GHG_{PI}$$

Where,			Units
GHG	=	Net GHG benefit from the project	MT CO_2e
GHG_{CSC}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Planting (from Equation 1)	MT CO_2e
GHG_{CSI}	=	GHG benefit of carbon stored in live project trees estimated using i-Tree Streets (from Equation 2)	MT CO_2e
GHG_{ESC}	=	GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3)	MT CO_2e
GHG_{ESI}	=	GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4)	MT CO_2e
GHG_{WP}	=	GHG benefit of carbon stored in wood products (from Equation 12)	MT CO_2e
GHG_{EG}	=	GHG benefit from utilizing biomass for energy generation (from Equation 16)	MT CO_2e
GHG_{L}	=	GHG benefit from preventing the landfilling of biomass (from Equation 23)	MT CO_2e
GHG_{PI}	=	GHG emissions from tree planting project implementation (from Equation 5)	MT CO_2e

M. Net Air Pollutant Co-benefit

The net air pollutant emission co-benefits from any project is the sum of the individual air pollutant emissions absorbed by planted trees, emission reductions from energy savings, benefit of wood stored in live project trees, and the benefit of using biomass for electricity generation. Equations 25 through 27 are used to determine the net air pollutant emission co-benefits from urban forestry projects.

Equation 25: $PM_{2.5}$ Net Emissions Benefit

$$PM_{2.5} = PM_{2.5,TA} + PM_{2.5,ES} + PM_{2.5,WP} + PM_{2.5,EC} + PM_{2.5,EG}$$

Where,			Units
$PM_{2.5}$	=	Net $PM_{2.5}$ benefit from the project	lb
$PM_{2.5,TA}$	=	$PM_{2.5}$ benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 6)	lb
$PM_{2.5,ES}$	=	$PM_{2.5}$ benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 8)	lb
$PM_{2.5,WP}$	=	$PM_{2.5}$ reduction due to wood products (from Equation 13)	lb
$PM_{2.5,EC}$	=	$PM_{2.5}$ reduction due to biomass combustion (from Equation 17)	lb
$PM_{2.5,EG}$	=	$PM_{2.5}$ reduction due to biomass gasification (from Equation 20)	lb

Equation 26: NO_x Net Emissions Benefit

$$NO_X = NO_{X,TA} + NO_{x,ES} + NO_{x,WP} + NO_{x,EC} + NO_{x,EG}$$

Where,			Units
NO_x	=	Net NO_x benefit from the project	lb
$NO_{x,TA}$	=	NO_x benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 7)	lb
$NO_{x,ES}$	=	NO_x benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 9)	lb
$NO_{x,WP}$	=	NO_x reduction due to wood products (from Equation 14)	lb
$NO_{x,EC}$	=	NO_x reduction due to biomass combustion (from Equation 18)	lb
$NO_{x,EG}$	=	NO_x reduction due to biomass gasification (from Equation 21)	lb

Equation 27: ROG Net Emissions Benefit

$$ROG = ROG_{ES} + ROG_{WP} + ROG_{EC} + ROG_{EG}$$

Where,			Units
ROG	=	Net ROG benefit from the project	lb
ROG_{ES}	=	ROG benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 10)	lb
ROG_{WP}	=	ROG reduction due to wood products (from Equation 15)	lb
ROG_{EC}	=	ROG reduction due to biomass combustion (from Equation 19)	lb
ROG_{EG}	=	ROG reduction due to biomass gasification (from Equation 22)	lb

Section C. References

California Air Resources Board. (2018). *California Greenhouse Gas Emissions Inventory*. https://www.arb.ca.gov/cc/inventory/data/tables/ghg_inventory_sector_sum_2000-16.pdf

California Air Resources Board. (2017). *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities: Final Draft*. https://www.arb.ca.gov/cc/waste/waste.htm

California Air Resources Board. (2015). *Compliance Offset Protocol U.S. Forest Projects*. https://www.arb.ca.gov/cc/capandtrade/protocols/usforest/forestprotocol2015.pdf

California Air Resources Board & California Department of Resources, Recycling, and Recovery. (2013). *Biomass Conversion*. https://www.arb.ca.gov/cc/waste/biomassconversion.pdf

California Air Resources Board. (2009). *Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Forest Waste*. https://www.arb.ca.gov/fuels/lcfs/022709lcfs_forestw.pdf

California Energy Commission. (2018). *California Energy Almanac: California Electricity Data Facts, and Statistics*. https://www.energy.ca.gov/almanac/electricity_data/electricity_generation.html

Greg McPherson, Research Forester, US Forest Service (April 25, 2016) personal communication

Roman, L.A. (2014). How many trees are enough? Tree death and the urban canopy. *Scenario Journal*, *(04)*. http://www.fs.fed.us/nrs/pubs/jrnl/2014/nrs_2014_roman_001.pdf

Sonoma County Water Agency. (2013). *Feasibility of Using Residual Woody Biomass to Generate Electricity for Sonoma County*. https://www.sonomawater.org/programmatic-efforts

United States Department of Agriculture, Forest Service. *i-Tree Streets User's Manual v.5.0*. https://www.itreetools.org/resources/manuals/Streets_Manual_v5.pdf

United States Department of Agriculture, Forest Service. *i-Tree ECO Guide to Using the Forecast Model*. http://www.itreetools.org/resources/manuals/Ecov6_ManualsGuides/Ecov6Guide_UsingForecast.pdf

United States Department of Agriculture, Forest Service. *i-Tree Methods and Files [i-Tree Streets & STRATUM Resources: i Tree Streets Reference City Community Tree Guides]*. https://www.itreetools.org/resources/archives.php

U.S. Department of Agriculture Forest Service, Tree Guides (multiple publications). https://www.fs.fed.us/psw/topics/urban_forestry/products/tree_guides.shtml

United States Department of Agriculture, Forest Service. (1994). *Chicago's Urban Forest Ecosystem: Results of the Chicago Urban Forest Climate Project*. Radnor, PA: https://www.nrs.fs.fed.us/pubs/gtr/gtr_ne186.pdf

United States Department of Energy Information Administration. (1998). *Method for Calculating Carbon Sequestration by Trees in Urban and Suburban Settings.* Washington, D.C. http://www3.epa.gov/climatechange/Downloads/method-calculating-carbon-sequestration-trees-urban-and-suburban-settings.pdf

United States Environmental Protection Agency. (2017). *Emission Factors for Greenhouse Gas Inventories.* http://www.epa.gov/sites/production/files/2015-12/documents/emission-factors_nov_2015.pdf

United States Environmental Protection Agency. (2003). *AP 42, Compilation of Air Emissions Factors*, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, 1.6 Wood Residue Combustion In Boilers. https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s06.pdf

United States Environmental Protection Agency. (1998). *AP 42: Compilation of Air Emissions Factors*, Fifth Edition, Volume I, Chapter 1: External Combustion Sources, 1.4 Natural Gas Combustion. https://www3.epa.gov/ttn/chief/ap42/ch01/final/c01s04.pdf

United States Environmental Protection Agency. (1998). *AP 42: Compilation of Air Emissions Factors*, Fifth Edition, Volume I, Chapter 2: Solid Waste Disposal, 2.4, Municipal Solid Waste Landfills. https://www3.epa.gov/ttnchie1/ap42/ch02/final/c02s04.pdf

Western Regional Climate Center. *Western U.S. Local Climate Data (LCD) [California]* https://wrcc.dri.edu/Climate/west_lcd.php