Quantification Methodology

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

California Climate Investments

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<thead>
<tr>
<th>Acronym</th>
<th>Term</th>
</tr>
</thead>
<tbody>
<tr>
<td>Btu</td>
<td>British thermal unit</td>
</tr>
<tr>
<td>C</td>
<td>carbon</td>
</tr>
<tr>
<td>CARB</td>
<td>California Air Resources Board</td>
</tr>
<tr>
<td>Diesel PM</td>
<td>diesel particulate matter</td>
</tr>
<tr>
<td>g</td>
<td>grams</td>
</tr>
<tr>
<td>gal</td>
<td>gallons</td>
</tr>
<tr>
<td>GGRF</td>
<td>Greenhouse Gas Reduction Fund</td>
</tr>
<tr>
<td>GHG</td>
<td>greenhouse gas</td>
</tr>
<tr>
<td>kg</td>
<td>kilograms</td>
</tr>
<tr>
<td>kg C</td>
<td>Kilograms of carbon</td>
</tr>
<tr>
<td>kWh</td>
<td>kilowatt hours</td>
</tr>
<tr>
<td>lb</td>
<td>pounds</td>
</tr>
<tr>
<td>lb CO2e</td>
<td>pounds of carbon dioxide equivalent</td>
</tr>
<tr>
<td>MMBtu</td>
<td>one million British thermal units</td>
</tr>
<tr>
<td>MT</td>
<td>metric ton</td>
</tr>
<tr>
<td>MT CO2e</td>
<td>metric tons of carbon dioxide equivalent</td>
</tr>
<tr>
<td>MT C</td>
<td>metric tons of carbon</td>
</tr>
<tr>
<td>MWh</td>
<td>megawatt hour</td>
</tr>
<tr>
<td>NOx</td>
<td>nitrous oxide</td>
</tr>
<tr>
<td>PM10</td>
<td>particulate matter with a diameter less than 10 micrometers</td>
</tr>
<tr>
<td>PM2.5</td>
<td>particulate matter with a diameter less than 2.5 micrometers</td>
</tr>
<tr>
<td>ROG</td>
<td>reactive organic gas</td>
</tr>
<tr>
<td>scf</td>
<td>standard cubic feet</td>
</tr>
<tr>
<td>short ton</td>
<td>common ton (US)</td>
</tr>
<tr>
<td>therm</td>
<td>one thousand British thermal units</td>
</tr>
<tr>
<td>UCF</td>
<td>Urban and Community Forestry</td>
</tr>
</tbody>
</table>
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](http://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](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.

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](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](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](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.

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\(^3\) 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/](http://ucanr.edu/sites/WUCOLS/Plant_Search/)

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. 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.

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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

<table>
<thead>
<tr>
<th>Project Activity</th>
<th>Net GHG Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tree Planting</td>
<td>$Net\ GHG\ benefit = carbon\ storage\ in\ planted\ trees - carbon\ in\ planted\ trees\ not\ assumed\ to\ survive^{6} + GHG\ reductions\ from\ energy\ savings\ from\ shade^{7} - GHG\ emissions\ from\ tree\ planting\ and\ maintenance$</td>
</tr>
<tr>
<td>Biomass Utilization for Wood Products</td>
<td>$Net\ GHG\ Benefit = carbon\ stored\ long-term\ in\ wood\ products + avoided\ GHG\ emissions\ from\ landfills - GHG\ emissions\ from\ mill$</td>
</tr>
<tr>
<td>Biomass Utilization for Electricity Generation</td>
<td>$Net\ GHG\ Benefit = avoided\ GHG\ emissions\ from\ displaced\ fossil\ fuel\ energy + avoided\ GHG\ emissions\ from\ landfills - GHG\ emissions\ from\ biomass\ facility$</td>
</tr>
</tbody>
</table>

**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.

<table>
<thead>
<tr>
<th>Equation 1: GHG Benefit of Carbon Stored in Live Project Trees (i-Tree Planting)</th>
</tr>
</thead>
</table>
| \[
  GHG_{CSC} = \frac{\sum_i C_{ITP,i} \times (1-0.03)^{10-YC}}{2,204.62}
\] |
| **Where,** |
| \(GHG_{CSC} = \) & GHG benefit of carbon stored in live project trees estimated using i-Tree Planting |
| \(C_{ITP,i} = \) & Carbon stored in each group of project trees (i), over the 40 year quantification period (from i-Tree Planting) |
| 0.03 = & Mortality rate (3% annual) |
| 10 = & Years after planting with greatest risk for mortality |
| 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) |
| \(i = \) & Project tree planted |
| \(2,204.62 = \) & Conversion factor from lb to MT |
| **Units,** |
| MT \(\text{CO}_2\text{e} = \) & |
| lb \(\text{CO}_2\text{e} = \) & |
| years = & |


\(^9\) 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,

- \( GHG_{CSI} \) = GHG benefit of carbon stored in live project trees estimated using i-Tree Streets
- \( C_{ITS} \) = Total carbon stored in population of project trees 40 years after project start (from i-Tree Streets)
- 0.03 = Mortality rate (3% annual)
- 10 = Years after planting with greatest risk for mortality
- 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)
- 2,204.62 = Conversion factor from lb to MT

Units
- MT CO\textsubscript{2}e
- lb CO\textsubscript{2}e
- years
- 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)**

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

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(GHG_{ESC})</td>
<td>GHG benefit from energy savings estimated using i-Tree Planting</td>
</tr>
<tr>
<td>(ER_{ITP,i})</td>
<td>Total electricity reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)</td>
</tr>
<tr>
<td>(EF_{ELEC})</td>
<td>GHG emission factor for electricity</td>
</tr>
<tr>
<td>1,000</td>
<td>Conversion factor from kWh to MWh</td>
</tr>
<tr>
<td>(NG_{ITP,i})</td>
<td>Total annual natural gas reductions from each group of project trees over the 40 year quantification period (from i-Tree Planting)</td>
</tr>
<tr>
<td>10</td>
<td>Conversion factor from MMBtu to therms</td>
</tr>
<tr>
<td>(EF_{NG})</td>
<td>GHG emission factor for natural gas</td>
</tr>
<tr>
<td>0.03</td>
<td>Mortality rate (3% annual)</td>
</tr>
<tr>
<td>10</td>
<td>Years after planting with greatest risk for mortality</td>
</tr>
<tr>
<td>(Y_C)</td>
<td>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)</td>
</tr>
<tr>
<td>(i)</td>
<td>Group of project trees planted</td>
</tr>
</tbody>
</table>

---

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

\[ \text{GHG}_{\text{ESI}} = (ER_{\text{ITS}} \times EF_{\text{ELEC}} + NG_{\text{ITS}} \times EF_{\text{NG}}) \times (1 - 0.03)^{10-\text{YC}} \times \text{Shade \%} \times 20 \]

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>GHG_{\text{ESI}}</td>
<td>GHG benefit from energy savings estimated using i-Tree Streets</td>
</tr>
<tr>
<td>ER_{\text{ITS}}</td>
<td>Total annual electricity reductions from population of project trees</td>
</tr>
<tr>
<td>EF_{\text{ELEC}}</td>
<td>GHG emission factor for electricity</td>
</tr>
<tr>
<td>NG_{\text{ITS}}</td>
<td>Total annual natural gas reductions from population of project trees</td>
</tr>
<tr>
<td>EF_{\text{NG}}</td>
<td>GHG emission factor for natural gas</td>
</tr>
<tr>
<td>0.03</td>
<td>Mortality rate (3% annual)</td>
</tr>
<tr>
<td>10</td>
<td>Years after planting with greatest risk for mortality</td>
</tr>
<tr>
<td>YC</td>
<td>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)</td>
</tr>
<tr>
<td>Shade %</td>
<td>Percent of trees planted to shade buildings (i.e., within 60 feet)</td>
</tr>
<tr>
<td>20</td>
<td>Years adjusted for annual energy savings output at year 40</td>
</tr>
</tbody>
</table>
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% 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**

\[
GHG_{PI} = \left( GHG_{CSC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI} \right) \times EF_{IMP}
\]

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(GHG_{PI})</td>
<td>GHG emissions from tree planting</td>
</tr>
<tr>
<td>(GHG_{CSC})</td>
<td>GHG benefit from carbon stored in live project trees estimated using i-Tree Planting (from Equation 1)</td>
</tr>
<tr>
<td>(GHG_{CSI})</td>
<td>GHG benefit from carbon stored in live project trees estimated using i-Tree Streets (from Equation 2)</td>
</tr>
<tr>
<td>(GHG_{ESC})</td>
<td>GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3)</td>
</tr>
<tr>
<td>(GHG_{ESI})</td>
<td>GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4)</td>
</tr>
<tr>
<td>(EF_{IMP})</td>
<td>Emission factor for project emissions</td>
</tr>
</tbody>
</table>

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.

---

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**

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

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PM_{2.5,TA}$</td>
<td>PM$_{2.5}$ benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets</td>
</tr>
<tr>
<td>$ER_{PM,ITP}$</td>
<td>Total PM$_{2.5}$ savings over the 40 year quantification period calculated from i-Tree Planting</td>
</tr>
<tr>
<td>$ER_{PM,ITS}$</td>
<td>Annual PM$_{10}$ savings 40 years after project start calculated from i-Tree Streets</td>
</tr>
<tr>
<td>20</td>
<td>Years adjusted for annual savings output at year 40</td>
</tr>
<tr>
<td>0.28</td>
<td>Conversion from PM$<em>{10}$ to PM$</em>{2.5}$</td>
</tr>
<tr>
<td>0.03</td>
<td>Mortality rate (3% annual)</td>
</tr>
<tr>
<td>10</td>
<td>Years after planting with greatest risk for mortality</td>
</tr>
<tr>
<td>YC</td>
<td>Years of establishment and replacement care provided by project</td>
</tr>
</tbody>
</table>

(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.)
### Equation 7: NO\textsubscript{x} Emissions Co-benefit from Tree Absorption

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

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NO_{x,TA})</td>
<td>(NO_x) benefit of tree planting in live project trees estimated using i-Tree Planting and i-Tree Streets</td>
</tr>
<tr>
<td>(ER_{NOx,ITP})</td>
<td>Total (NO_x) savings over the 40 year quantification period calculated from i-Tree Planting</td>
</tr>
<tr>
<td>(ER_{NOx,ITS})</td>
<td>Annual (NO_x) savings 40 years after project start calculated from i-Tree Streets</td>
</tr>
<tr>
<td>20</td>
<td>Years adjusted for annual savings output at year 40</td>
</tr>
<tr>
<td>0.03</td>
<td>Mortality rate (3% annual)</td>
</tr>
<tr>
<td>10</td>
<td>Years after planting with greatest risk for mortality</td>
</tr>
<tr>
<td>(YC)</td>
<td>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)</td>
</tr>
</tbody>
</table>
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

\[ PM_{2.5,ES} = \left( (ER_{ITP} + (ER_{ITS} \times Shade \% \times 20 \times 1,000)) \times PM_{ELEC} + (NG_{ITP} + (NG_{ITS} \times Shade \% \times 0.1 \times 20)) \times PM_{NG} \right) \times (1 - 0.03)^{10-YC} \]

Where,

\begin{align*}
PM_{2.5,ES} & = \text{PM$_{2.5}$ benefit from energy savings estimated using i-Tree Planting and i-Tree Streets} \\
ER_{ITP} & = \text{Total energy savings over the 40 year quantification period calculated from i-Tree Planting} \\
ER_{ITS} & = \text{Annual energy savings 40 years after project start calculated from i-Tree Streets} \\
Shade \% & = \text{The percent of the trees planted to shade buildings (i.e. within 60 ft); for users of i-Tree Streets} \\
20 & = \text{Years adjusted for annual energy savings output at year 40} \\
1,000 & = \text{Conversion factor from MWh to kWh} \\
PM_{ELEC} & = \text{PM$_{2.5}$ emission factor for electricity} \\
NG_{ITP} & = \text{Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting} \\
NG_{ITS} & = \text{Annual natural gas savings 40 years after project start calculated from i-Tree Streets} \\
0.1 & = \text{Conversion from therms to MMBtu} \\
PM_{NG} & = \text{PM$_{2.5}$ emission factor for natural gas} \\
0.03 & = \text{Mortality rate (30% annual)} \\
10 & = \text{Years after planting with greatest risk for mortality} \\
YC & = \text{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)}
\end{align*}

Units

- lb
- kWh
- MWh
- %
- years
- kWh/MWh
- lb/kWh
- MMBtu
- therms
- MMBtu/therm
- lb/MMBtu
- years
- years
**Equation 9: NO\textsubscript{x} Emissions Co-benefit from Energy Savings**

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

*Where,*

- **NO\textsubscript{x,ES}** = NO\textsubscript{x} benefit from energy savings estimated using i-Tree Planting and i-Tree Streets
- **ER\textsubscript{ITP}** = Total energy savings over the 40 year quantification period calculated from i-Tree Planting
- **ER\textsubscript{ITS}** = Annual energy savings 40 years after project start calculated from i-Tree Streets
- **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
- **1,000** = Conversion factor from MWh to kWh
- **NOX\textsubscript{ELEC}** = NO\textsubscript{x} emission factor for electricity
- **NG\textsubscript{ITP}** = Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting
- **NG\textsubscript{ITS}** = Annual natural gas savings 40 years after project start calculated from i-Tree Streets
- **0.1** = Conversion from therms to MMBtu
- **NOX\textsubscript{NG}** = NO\textsubscript{x} emission factor for natural gas
- **0.03** = Mortality rate (3% annual)
- **10** = Years after planting with greatest risk for mortality
- **YC** = Years of establishment and replacement care provided by project

*Units*

- lb
- kWh
- MWh
- %
- years
- kWh/MWh
- lb/kWh
- MMBtu
- therms
- MMBtu/therm
- lb/MMBtu
- years
**Equation 10: ROG Emissions Co-benefit from Energy Savings**

\[
ROG_{ES} = \left(\left(ER_{ITP} + (ER_{ITS} \times Shade \% \times 20 \times 1.000)\right) \times ROG_{ELEC} + (NG_{ITP} + (NG_{ITS} \times Shade \% \times 0.1 \times 20)) \times ROG_{NG}\right) \times (1 - 0.03)^{10-YC}
\]

*Where,*

- \(ROG_{ES}\) = ROG benefit from energy savings estimated using i-Tree Planting and i-Tree Streets
- \(ER_{ITP}\) = Total energy savings over the 40 year quantification period calculated from i-Tree Planting
- \(ER_{ITS}\) = Annual energy savings calculated from i-Tree Streets
- \(Shade \%\) = 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
- 1,000 = Conversion factor from MWh to kWh
- \(ROG_{ELEC}\) = ROG emission factor for electricity
- \(NG_{ITP}\) = Total natural gas savings over the 40 year quantification period calculated from i-Tree Planting
- \(NG_{ITS}\) = Annual natural gas savings 40 years after project start calculated from i-Tree Streets
- 0.1 = Conversion from therms to MMBtu
- \(ROG_{NG}\) = ROG emission factor for natural gas
- 0.03 = Mortality rate (3% annual)
- 10 = Years after planting with greatest risk for mortality
- \(YC\) = Years of establishment and replacement care provided by project

*Units*

- \(ROG_{ES}\) = Ib
- \(ER_{ITP}\) = kWh
- \(ER_{ITS}\) = MWh
- \(Shade \%\) = %
- 20 = years
- 1,000 = kWh/MWh
- \(ROG_{ELEC}\) = Ib/kWh
- \(NG_{ITP}\) = MMBtu
- \(NG_{ITS}\) = therms
- 0.1 = MMBtu/therm
- \(ROG_{NG}\) = Ib/MMBtu
- 0.03 =
- 10 = years
- \(YC\) = years

*Notes:

1. 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.*
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, 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

\[ C_{WP} = \sum_i \left( \frac{AGB_{ITP,W Pi} \times 907.18474 \times 0.5}{1,000} \right) \times ME \]

Where,

- \( C_{WP} \) = Carbon transferred to wood products (Units: MT C)
- \( AGB_{ITP,W Pi} \) = 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)
- 907.18474 = Conversion factor from short ton to kg
- 0.5 = Removed project tree to be utilized for wood products
- 1,000 = Conversion factor from kg to MT
- ME = Mill efficiency

Table 2. Default Mill Efficiency

<table>
<thead>
<tr>
<th></th>
<th>Hardwood</th>
<th>Softwood</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>56.8%</td>
<td>67.5%</td>
</tr>
</tbody>
</table>

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. 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**

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

Where,  

<table>
<thead>
<tr>
<th>Variable</th>
<th>Description</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(GHG_{\text{WP}})</td>
<td>GHG benefit of carbon stored in wood products</td>
<td>MT CO(_2)e</td>
</tr>
<tr>
<td>(C_{\text{WP}})</td>
<td>Carbon transferred to wood products (from Equation 11)</td>
<td>MT C</td>
</tr>
<tr>
<td>SL</td>
<td>Percentage of biomass that will go into softwood lumber</td>
<td>%</td>
</tr>
<tr>
<td>0.463</td>
<td>Carbon storage factor for softwood lumber</td>
<td></td>
</tr>
<tr>
<td>HL</td>
<td>Percentage of biomass that will go into hardwood lumber</td>
<td>%</td>
</tr>
<tr>
<td>0.250</td>
<td>Carbon storage factor for hardwood lumber</td>
<td></td>
</tr>
<tr>
<td>SP</td>
<td>Percentage of biomass that will go into softwood plywood</td>
<td>%</td>
</tr>
<tr>
<td>0.484</td>
<td>Carbon storage factor for softwood plywood</td>
<td></td>
</tr>
<tr>
<td>OS</td>
<td>Percentage of biomass that will go into oriented strand board</td>
<td>%</td>
</tr>
<tr>
<td>0.582</td>
<td>Carbon storage factor for oriented strand board</td>
<td></td>
</tr>
<tr>
<td>NP</td>
<td>Percentage of biomass that will go into nonstructural panels</td>
<td>%</td>
</tr>
<tr>
<td>0.380</td>
<td>Carbon storage factor for nonstructural panels</td>
<td></td>
</tr>
<tr>
<td>P</td>
<td>Percentage of biomass that will go into paper</td>
<td>%</td>
</tr>
<tr>
<td>0.058</td>
<td>Carbon storage factor for paper</td>
<td></td>
</tr>
<tr>
<td>MP</td>
<td>Percentage of biomass that will go into miscellaneous products</td>
<td>%</td>
</tr>
<tr>
<td>0.176</td>
<td>Carbon storage factor for miscellaneous products</td>
<td></td>
</tr>
<tr>
<td>3.67</td>
<td>Conversion factor from C to CO(_2)e</td>
<td>CO(_2)e/C</td>
</tr>
</tbody>
</table>
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,

<table>
<thead>
<tr>
<th>$PM_{2.5, WP}$</th>
<th>PM$_{2.5}$ benefit from wood products</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AGB_{ITP, WP}$</td>
<td>Total biomass calculated from i-Tree Planting</td>
<td>short tons</td>
</tr>
<tr>
<td>$PM_{FLARE}$</td>
<td>PM$_{2.5}$ flare combustion emission factor</td>
<td>lb/wet short ton</td>
</tr>
<tr>
<td>0.52</td>
<td>Average dry weight percentage for tree biomass</td>
<td>dry ton/wet ton</td>
</tr>
</tbody>
</table>

**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,

<table>
<thead>
<tr>
<th>$NO_x, WP$</th>
<th>NO$_x$ benefit from wood products</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AGB_{ITP, WP}$</td>
<td>Total biomass calculated from i-Tree Planting</td>
<td>short tons</td>
</tr>
<tr>
<td>$NOX_{FLARE}$</td>
<td>NO$_x$ flare combustion emission factor</td>
<td>lb/wet short ton</td>
</tr>
<tr>
<td>0.52</td>
<td>Average dry weight percentage for tree biomass</td>
<td>dry ton/wet ton</td>
</tr>
</tbody>
</table>

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

\[
ROG, WP = AGB_{ITP, WP} \times \frac{ROG_{FLARE}}{0.52}
\]

Where,

<table>
<thead>
<tr>
<th>$ROG, WP$</th>
<th>ROG benefit from wood products</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$AGB_{ITP, WP}$</td>
<td>Total biomass calculated from i-Tree Planting</td>
<td>short tons</td>
</tr>
<tr>
<td>$ROG_{FLARE}$</td>
<td>ROG flare combustion emission factor</td>
<td>lb/wet short ton</td>
</tr>
<tr>
<td>0.52</td>
<td>Average dry weight percentage for tree biomass</td>
<td>dry ton/wet ton</td>
</tr>
</tbody>
</table>
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**

\[ GHG_{EG} = \sum_i \left( AGB_{ITP,EG,i} \right) \times GHG_{COMBUST} + \sum_i \left( AGB_{ITP,EG,i} \right) \times GHG_{GAS} \]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>( GHG_{EG} )</td>
<td>GHG benefit from utilizing biomass for electricity generation</td>
</tr>
<tr>
<td>( AGB_{ITP,EG,i} )</td>
<td>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)</td>
</tr>
<tr>
<td>( GHG_{COMBUST} )</td>
<td>Emission reduction factor for combustion</td>
</tr>
<tr>
<td>( AGB_{ITP,EG,i} )</td>
<td>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)</td>
</tr>
<tr>
<td>( GHG_{GAS} )</td>
<td>Emission reduction factor for gasification</td>
</tr>
<tr>
<td>( i )</td>
<td>Removed group of project trees to be utilized for electricity generation</td>
</tr>
</tbody>
</table>
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**

\[
PM_{2.5,\text{EC}} = (AGB_{\text{ITP,EC}} \times 0.9 \times 1.000 \times PM_{\text{ELEC}}) + \left(AGB_{\text{ITP,EC}} \times \frac{PM_{\text{FLARE}}}{0.52}\right) - \left(AGB_{\text{ITP,EC}} \times 0.9 \times 1.000 \times PM_{\text{COMBUST}} \times 0.66\right)
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$PM_{2.5,\text{EC}}$</td>
<td>PM$_{2.5}$ benefit from biomass combustion</td>
</tr>
<tr>
<td>$AGB_{\text{ITP,EC}}$</td>
<td>Total biomass calculated from i-Tree Planting</td>
</tr>
<tr>
<td>0.9</td>
<td>MWh per ton of biomass waste</td>
</tr>
<tr>
<td>1,000</td>
<td>Conversion from MWh to kWh</td>
</tr>
<tr>
<td>$PM_{\text{ELEC}}$</td>
<td>PM$_{2.5}$ electricity emission factor</td>
</tr>
<tr>
<td>$PM_{\text{FLARE}}$</td>
<td>PM$_{2.5}$ flare combustion emission factor</td>
</tr>
<tr>
<td>0.52</td>
<td>Average dry weight percentage for tree biomass</td>
</tr>
<tr>
<td>$PM_{\text{COMBUST}}$</td>
<td>PM biomass combustion factor</td>
</tr>
<tr>
<td>0.66</td>
<td>Conversion from PM to PM$_{2.5}$</td>
</tr>
</tbody>
</table>

**Equation 18: NO$_x$ Emissions Co-benefit from Biomass Electricity Generation via Combustion**

\[
NO_x,\text{EC} = (AGB_{\text{ITP,EC}} \times 0.9 \times 1.000 \times NOX_{\text{ELEC}}) + \left(AGB_{\text{ITP,EC}} \times \frac{NOX_{\text{FLARE}}}{0.52}\right) - \left(AGB_{\text{ITP,EC}} \times 0.9 \times 1.000 \times NOX_{\text{COMBUST}}\right)
\]

<table>
<thead>
<tr>
<th>Where,</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>$NO_x,\text{EC}$</td>
<td>NO$_x$ benefit from biomass combustion</td>
</tr>
<tr>
<td>$AGB_{\text{ITP,EC}}$</td>
<td>Total biomass calculated from i-Tree Planting</td>
</tr>
<tr>
<td>0.9</td>
<td>MWh per ton of biomass waste</td>
</tr>
<tr>
<td>1,000</td>
<td>Conversion from MWh to kWh</td>
</tr>
<tr>
<td>$NOX_{\text{ELEC}}$</td>
<td>NO$_x$ electricity emission factor</td>
</tr>
<tr>
<td>$NOX_{\text{FLARE}}$</td>
<td>NO$_x$ flare combustion emission factor</td>
</tr>
<tr>
<td>0.52</td>
<td>Average dry weight percentage for tree biomass</td>
</tr>
<tr>
<td>$NOX_{\text{COMBUST}}$</td>
<td>NO$_x$ biomass combustion factor</td>
</tr>
</tbody>
</table>
Equation 19: ROG Emissions Co-benefit from Biomass Electricity Generation via Combustion

\[ ROG_{EC} = (AGB_{ITP,EC} \times 0.9 \times 1.000 \times ROG_{ELEC}) + \left(AGB_{ITP,EC} \times \frac{ROG_{FLARE}}{0.52}\right) - \left(AGB_{ITP,EC} \times 0.9 \times 1.000 \times ROG_{COMBUST}\right) \]

Where,

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

Units:

- lb
- short tons
- MWh/ton of biomass
- kWh/MWh
- lb/kWh
- lb/wet short ton green waste
- dry ton/wet ton
- lb/kWh
J. Air Pollutant Co-benefit from Utilizing Biomass for Electric 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**

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

Where,  
\begin{align*}
PM_{2.5,EG} &: PM_{2.5} \text{ benefit from biomass gasification} \\
AGB_{TP,EG} &: \text{Total biomass calculated from i-Tree Planting} \\
0.9 &: \text{MWh per ton of biomass waste} \\
1,000 &: \text{Conversion factor from MWh to kWh} \\
PM_{ELEC} &: \text{PM}_{2.5} \text{ electricity emission factor} \\
PM_{FLARE} &: \text{PM}_{2.5} \text{ flare combustion emission factor} \\
0.52 &: \text{Average dry weight percentage for tree biomass} \\
PM_{GAS} &: \text{PM biomass gasification factor} \\
0.66 &: \text{Conversion from PM to PM}_{2.5} \\
\end{align*}

Units:  
\begin{align*}
lb & \quad \text{PM}_{2.5} \\
\text{short tons} & \quad \text{AGB} \\
\text{MWh/ton of biomass} & \quad 0.9 \\
kWh & \quad 1,000 \\
lb/kWh & \quad PM_{ELEC} \\
lb/wet short ton green waste & \quad PM_{FLARE} \\
dry ton/wet ton & \quad 0.52 \\
lb/kWh & \quad PM_{GAS} \\
\end{align*}

**Equation 21: NO$_x$ Emissions Co-benefit from Biomass Electricity Generation via Gasification**

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

Where,  
\begin{align*}
NO_{x,EG} &: NO_x \text{ benefit from biomass gasification} \\
AGB_{TP,EG} &: \text{Total biomass calculated from i-Tree Planting} \\
0.9 &: \text{MWh per ton of biomass waste} \\
1,000 &: \text{Conversion from MWh to kWh} \\
NOX_{ELEC} &: NO_x \text{ electricity emission factor} \\
NOX_{FLARE} &: NO_x \text{ flare combustion emission factor} \\
0.52 &: \text{Average dry weight percentage for tree biomass} \\
NOX_{GAS} &: NO_x \text{ biomass gasification factor} \\
\end{align*}

Units:  
\begin{align*}
lb & \quad NO_x \\
\text{short tons} & \quad AGB \\
\text{MWh/ton of biomass} & \quad 0.9 \\
kWh & \quad 1,000 \\
lb/kWh & \quad NOX_{ELEC} \\
lb/wet short ton green waste & \quad NOX_{FLARE} \\
dry ton/wet ton & \quad 0.52 \\
lb/kWh & \quad NOX_{GAS} \\
\end{align*}
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,  

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

- \(GHG_L\): GHG benefit from preventing the landfilling of biomass
- \(AGB_{ITP,WP,i}\): Aboveground biomass of project tree (i) at time of removal to be utilized for wood products (weight from i-Tree Planting)
- \(AGB_{ITP,EC,i}\): Aboveground biomass of project tree (i) at time of removal to be utilized for electricity generation via combustion (weight from i-Tree Planting)
- \(AGB_{ITP,EG,i}\): Aboveground biomass of project tree (i) at time of removal to be utilized for electricity generation via gasification (weight from i-Tree Planting)
- \(i\): Removed group of project trees to be utilized
- \(GHG_{LANDFILL}\): Avoided landfill emission reduction factor
- 0.52: Average dry weight percentage for tree biomass

Units:
- MT CO\(_{2e}\)
- short ton
- MT CO\(_{2e}\)/wet short ton
- 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.

\[
GHG = (GHG_{SC} + GHG_{CSI} + GHG_{ESC} + GHG_{ESI} + GHG_{WP} + GHG_{EG} + GHG_{L}) - GHG_{PI}
\]

Where,
- GHG: Net GHG benefit from the project, units: MT CO₂e
- GHG_{SC}: GHG benefit of carbon stored in live project trees estimated using i-Tree Planting (from Equation 1), units: MT CO₂e
- GHG_{CSI}: GHG benefit of carbon stored in live project trees estimated using i-Tree Streets (from Equation 2), units: MT CO₂e
- GHG_{ESC}: GHG benefit from energy savings estimated using i-Tree Planting (from Equation 3), units: MT CO₂e
- GHG_{ESI}: GHG benefit from energy savings estimated using i-Tree Streets (from Equation 4), units: MT CO₂e
- GHG_{WP}: GHG benefit of carbon stored in wood products (from Equation 12), units: MT CO₂e
- GHG_{EG}: GHG benefit from utilizing biomass for energy generation (from Equation 16), units: MT CO₂e
- GHG_{L}: GHG benefit from preventing the landfilling of biomass (from Equation 23), units: MT CO₂e
- GHG_{PI}: GHG emissions from tree planting project implementation (from Equation 5), units: MT CO₂e
### 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**

\[
PM_{2.5} = PM_{2.5,T_A} + PM_{2.5,ES} + PM_{2.5,WP} + PM_{2.5,EC} + PM_{2.5,EG}
\]

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(PM_{2.5})</td>
<td>Net (PM_{2.5}) benefit from the project</td>
</tr>
<tr>
<td>(PM_{2.5,T_A})</td>
<td>(PM_{2.5}) benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 6)</td>
</tr>
<tr>
<td>(PM_{2.5,ES})</td>
<td>(PM_{2.5}) benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 8)</td>
</tr>
<tr>
<td>(PM_{2.5,WP})</td>
<td>(PM_{2.5}) reduction due to wood products (from Equation 13)</td>
</tr>
<tr>
<td>(PM_{2.5,EC})</td>
<td>(PM_{2.5}) reduction due to biomass combustion (from Equation 17)</td>
</tr>
<tr>
<td>(PM_{2.5,EG})</td>
<td>(PM_{2.5}) reduction due to biomass gasification (from Equation 20)</td>
</tr>
</tbody>
</table>

**Equation 26: NO\(_x\) Net Emissions Benefit**

\[
NO_x = NO_{x,T_A} + NO_{x,ES} + NO_{x,WP} + NO_{x,EC} + NO_{x,EG}
\]

<table>
<thead>
<tr>
<th>Where</th>
<th>Units</th>
</tr>
</thead>
<tbody>
<tr>
<td>(NO_x)</td>
<td>Net (NO_x) benefit from the project</td>
</tr>
<tr>
<td>(NO_{x,T_A})</td>
<td>(NO_x) benefit of tree absorption in live project trees estimated using i-Tree Planting or i-Tree Streets (from Equation 7)</td>
</tr>
<tr>
<td>(NO_{x,ES})</td>
<td>(NO_x) benefit from energy savings estimated using i-Tree Planting or i-Tree Streets (from Equation 9)</td>
</tr>
<tr>
<td>(NO_{x,WP})</td>
<td>(NO_x) reduction due to wood products (from Equation 14)</td>
</tr>
<tr>
<td>(NO_{x,EC})</td>
<td>(NO_x) reduction due to biomass combustion (from Equation 18)</td>
</tr>
<tr>
<td>(NO_{x,EG})</td>
<td>(NO_x) reduction due to biomass gasification (from Equation 21)</td>
</tr>
</tbody>
</table>
**Equation 27: ROG Net Emissions Benefit**

\[
ROG = ROG_{ES} + ROG_{WP} + ROG_{EC} + ROG_{EG}
\]

**Where,**

| \(ROG\) | 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


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


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