California Air Resources Board

Quantification Methodology

Forest Restoration & Management

California Climate Investments

April 26, 2021

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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: http://www.arb.ca.gov/cci-expenditurerecords.

California Air Resources Board (CARB) staff developed the Forest Restoration and Management Quantification Methodology to provide guidance for estimating the net GHG benefit of forest restoration and management activities including reforestation, forest pest management, fuels reduction, forest conservation, and biomass utilization. Calculations account for on-site forest carbon stocks, carbon stored in wood products, the displacement of fossil fuels that results from biomass energy generation, and GHG emissions associated with the implementation of forest restoration and management projects.

The Forest Restoration and Management Benefits Calculator Tool automates methods described in this document, provides a link to a step-by-step user guide with an example project example, and outlines documentation requirements. Projects will report the total project GHG benefit and co-benefits estimated using the Forest Restoration and Management Benefits Tool as well as the total project GHG benefit per dollar of GGRF funds requested. The Forest Restoration and Management 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 Forest Restoration and Management Benefits Calculator Tool also estimates co-benefits and key variables. Soil health and conservation (acres) is quantified as a co-benefit. Key variables are project characteristics that contribute to a project's net GHG benefit and signal an additional benefit. Key variables included in the Forest Restoration and Management Benefits Calculator include: number of trees planted, area restored or treated for reforestation, pest management and/or fuels reduction activities in acres, area conserved via conservation easements in acres, and renewable energy generated via biomass utilization in kWh. Additional co-benefits for which CARB assessment methodologies were not incorporated into the Forest Restoration and Management

Benefits Calculator Tool may also be applicable to the project. Applicants should consult the program guidelines, solicitation materials, and agreements to ensure they are meeting program requirements. All CARB co-benefit assessment methodologies are available at: http://www.arb.ca.gov/cci-cobenefits.

Methodology Development

CARB and the Department of Forestry and Fire Protection (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 Forest Restoration and Management 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 project types. 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.

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, lessening the impacts and effects of climate change, and strengthening community engagement. Co-benefit assessment methodologies are posted at: http://www.arb.ca.gov/cci-cobenefits.

Tools

The Forest Restoration and Management Benefits Calculator Tool relies on project-specific outputs from the following tools:

Tree growth and yield models simulate a range of silvicultural treatments and provide carbon stock estimates based on individual tree and stand data. The Forest Restoration and Management Benefits Calculator Tool User Guide provides guidance for using the USFS Forest Vegetation Simulator (FVS), but applicants may choose to use alternative models including: Forest and Stand Evaluation Environment (FORSEE), California

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[1] California Air Resources Board. California Climate Investments Funding Guidelines

Conifer Timber Output Simulator (CACTOS), Stand Projection System (SPS), or Forest Projection System (FPS). Growth and yield models can be used by applicants to estimate carbon stocks for reforestation, pest management, fuels reduction and forest conservation activities within a forest restoration and management project. The FVS model is used statewide, publicly available, subject to regular updates to incorporate new information, is free of charge, and available to anyone with internet access. The FVS model can be accessed at: http://www.fs.fed.us/fvs/.

Forest fire models simulate fire behavior and effects including impacts on carbon stocks. The Forest Restoration and Management Benefits Calculator Tool User Guide provides guidance for using two federal tools, the Fire and Fuels Extension of FVS (FFE-FVS) and the Interagency Fuel Treatment Decision Support System (IFTDSS), but applicants may choose to use alternative models including FlamMap, Consume, and First Order Fire Effects Model (FOFEM). Wildland fire models can be used by applicants to estimate reduced loss in carbon stocks from wildfire for fuels reduction activities within a forest restoration and management project. FFE-FVS and IFTDSS are used statewide, publicly available, subject to regular updates to incorporate new information, free of charge, and available to anyone with internet access. The FFE-FVS model can be accessed at: http://www.fs.fed.us/fvs/. The IFTDSS Tool can be accessed at: https://iftdss.firenet.gov/

Applicants will choose from the appropriate tools listed for each activity in Table 2 of the Forest Restoration and Management Benefits Calculator Tool User Guide and do not need to use the same tools for all activities that comprise the project.

The Forest Restoration and Management Quantification Methodology previously included the Carbon On Line Estimator (COLE) Version 3.0 as a tool to estimate forest carbon stocks for reforestation, pest management, and avoided conversion forest conservation easement activities within a forest restoration and management project. The COLE tool is not currently available. Forest carbon stocks for reforestation, pest management, and avoided conversion conservation easements can be estimated with one of the approved forest growth and yield models. Alternately, CAL FIRE, in consultation with CARB, has used FVS simulations to generate tables that applicants can use to estimate forest carbon stocks resulting from reforestation activities. Applicants to the CAL FIRE Forest Health Program that would have used COLE to quantify forest carbon stocks for pest management and avoided conversion conservation easements can contact CAL FIRE to request FVS model estimates of forest carbon stocks in these project scenarios. *These requests must be received by CAL FIRE **at least three weeks prior** to the application deadline*. Send requests to ForestHealth@fire.ca.gov.

In addition to the tool above, the Forest Restoration and Management 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 Forest Restoration and Management Benefits Calculator Tool to estimate the net GHG benefit and co-benefits of the proposed project. The Forest Restoration and Management 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 Forest Restoration and Management Quantification Methodology from the previous version[2] to enhance the analysis and provide additional clarity. The changes include:

- The name of this Quantification Methodology has been changed from the "Forest Health Quantification Methodology" to the "Forest Restoration and Management Quantification Methodology" to reflect the applicability of these methods to projects funded by other California Climate Investments programs.

- To be consistent with other California Climate Investments quantification methodologies, the previous Quantification Methodology has been split into two documents: a User Guide that contains a step-by-step directions for completing the calculations and a project example, and a Quantification Methodology document that provides the equations and technical background supporting the Benefits Calculator Tool.

- Applicants are now encouraged to use the Interagency Fuel Treatment Decision Support System (IFTDSS) for quantifying changes in fire behavior created by fuels reduction activities. The Landscape Burn Probability[3] modeling portion of IFTDSS is an online implementation of the Minimum Travel Time (MTT) Burn Probability function of FlamMap 6.0, with some fixed modeling inputs. Instructions for IFTDSS are available online and in the Forest Restoration and Management Benefits Calculator User Guide.

- As a result of the shift to IFTDSS, the quantification of the benefits of fuels reduction activities has been modified. Previously, the methodology quantified the effect of a fuels reduction activity within the treatment area based on modeled tree growth and mortality, and in the surrounding forest (the impact area) solely based on the change in probability of high flame length in the impact area. Because the calculation of flame length probability in IFTDSS is conditional on fire occurrence, the revised quantification equation now also accounts for the potential of the fuels reduction treatment to decrease the probability that fire occurs within areas that would have otherwise burned at high severity. No benefit accrues for decreasing fire probability in areas that would burn with low or

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[2] The FY19-20 Forest Health Quantification Methodology is available upon request by emailing GGRFProgram@arb.ca.gov
[3] https://iftdss.firenet.gov/firenetHelp/help/pageHelp/content/20-models/lbp/about.htm

moderate flame length. Equation 8 in this quantification methodology has been revised accordingly.

- The User Guide now specifies that when conducting growth and yield modeling, applicants may include in their projections the ingrowth of natural regeneration in both the baseline and project scenarios.
- The Fire Probability Map for Fuels Management Activities has been updated based on improved modeling approaches and more recent fire history (through 2019) for California. More information on the update is available on the Fire and Resource Assessment Program's Fire Probability for Carbon Accounting webpage. https://egis.fire.ca.gov/FireProbability/

Section B. Methods

The following section provides details on the methods supporting emission reductions in the Forest Restoration and Management Benefits Calculator Tool.

Project Activities

Activities included within the Forest Restoration and Management Quantification Methodology achieve a net GHG benefit through forest management actions such as reforestation, pest management, fuels reduction, and conservation easements, which increase the amount of carbon stored within forests and may include forest biomass utilization activities that store carbon in wood products and/or reduce GHG emissions by generating energy. Other project features may be eligible for funding; however, each project requesting GGRF funding must include at least one of the following project activity types:

- Reforestation;
- Pest Management;
- Fuels Reduction;
- Forest Conservation Easement for Avoided Conversion or Improved Forest Management; and
- Biomass Utilization.

General Approach

Methods used in the Forest Restoration and Management Benefits Calculator Tool for estimating the net GHG benefit and 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.

This methodology uses calculations to estimate the net GHG benefit of forest management activities including reforestation, forest pest management, fuels reduction, forest conservation, and biomass utilization. Calculations account for on-site forest carbon stocks, carbon stored in wood products, the displacement of fossil fuels that results from biomass energy generation, and GHG emissions associated with the implementation of forest health projects. In general, the net GHG benefit is estimated in the Forest Restoration and Management Benefits Calculator Tool using the approaches in Table 1. The Forest Restoration and Management 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

Reforestation
Net GHG Benefit = Δ in standing live and dead tree carbon stocks (above and belowground) in the treatment boundary – carbon in shrubs and herbaceous understory removed from treatment boundary – emissions from site preparation and herbicide treatments

Pest Management
Net GHG Benefit = Δ in standing live tree carbon stocks (above and belowground) in the treatment and impact boundaries as a result of reduced mortality from pests and disease – carbon in biomass removed from treatment boundary – mobile combustion emissions from mechanical treatments

Fuels Reduction
Net GHG Benefit = Δ in standing live tree carbon stocks (above and belowground) in the treatment boundary and impact boundary (optional) as a result of reduced mortality from wildfire – carbon in biomass removed from treatment boundary – mobile combustion emissions from mechanical treatments

Forest Conservation (Avoided Conversion or Forest Management Easements)
Net GHG Benefit = Δ in standing live and dead tree carbon stocks (above and belowground) in the treatment boundary as a result of avoided conversion and/or changes in forest management[4]

Biomass Utilization
Net GHG Benefit = Carbon stored long-term in wood products + avoided emissions from fossil fuel-based energy displaced by biomass energy – stationary combustion emissions from biomass energy production + avoided emissions from alternative form of biomass disposal[5]

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[4] Forest conservation activities are expected to impact long-term biomass removal and utilization and therefore biomass that would be removed and utilized in the conservation baseline and project scenarios are calculated as part of the biomass utilization activity.

[5] Avoided biomass disposal emissions are only included for projects that involve the utilization of biomass that would otherwise be removed (i.e., biomass removal is not funded by GGRF) and landfilling, open pile burning or on-site decay is expected in the baseline scenario (i.e., in the absence of the project). The methodology does not account for avoided disposal emissions of material that would only require disposal as a result of the project.

A. GHG Benefit from Reforestation Activities

The GHG benefit from reforestation activities is calculated as the difference between the baseline and project scenarios using Equation 1. Equation 2 is used to determine the carbon storage and project emissions in the project scenario. Equation 3 is used to determine the carbon storage in the baseline scenario.

Equation 1: GHG Benefit from Reforestation Activities

$$GHG_R = GHG_{RP} - GHG_{RB}$$

Where,			*Units*
GHG_R	=	GHG benefit of reforestation activities	MT CO$_2$e
GHG_{RP}	=	On-site carbon storage and project emissions in reforestation project scenario (from Equation 2)	MT CO$_2$e
GHG_{RB}	=	On-site carbon storage in reforestation baseline scenario (from Equation 3)	MT CO$_2$e

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Equation 2: On-Site Carbon Storage and Project Emissions in Reforestation Project Scenario

$$GHG_{RP} = CT_{RP} \times 3.67 - MC_{RP} \times ASP_{RP} - AHT_{RP} \times 0.0607$$

Where,			*Units*
GHG_{RP}	=	On-site carbon storage and project emissions in reforestation project scenario	MT CO$_2$e
CT_{RP}	=	Carbon within the treatment boundary at the end of the project with reforestation	MT C
3.67	=	Conversion factor from C to CO$_2$e	CO$_2$e/C
MC_{RP}	=	Mobile combustion emission factor if site preparation takes place in reforestation project scenario (based on level of brush cover)	MT CO$_2$e/ Acre
ASP_{RP}	=	Area subject to site preparation	Acres
AHT_{RP}	=	Area subject to herbicide treatment	Acres
0.0607	=	Herbicide treatment emission factor	MT CO$_2$e/ Acre

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Equation 3: On-Site Carbon Storage in Reforestation Baseline Scenario

$$GHG_{RB} = CT_{RB} \times 3.67 + SHU_{RB} \times ASP_{RP}$$

Where,			*Units*
GHG_{RB}	=	On-site carbon storage in reforestation baseline scenario	MT CO$_2$e
CT_{RB}	=	Carbon within the treatment boundary at the end of the project without reforestation (from Baseline Reforestation Table within the Forest Restoration and Management Benefit Calculator Tool)	MT C
3.67	=	Conversion factor from C to CO$_2$e	CO$_2$e/C
SHU_{RB}	=	Shrubs and herbaceous understory carbon removed during site preparation from within the treatment boundary in reforestation project scenario (based on land cover type)	MTCO$_2$e/ Acre
ASP_{RP}	=	Area subject to site preparation	Acres

B. GHG Benefit from Pest Management Activities

The GHG benefit from pest management activities is calculated as the difference between the baseline and project scenarios using Equation 4. Equation 5 is used to determine the carbon storage and project emissions in the project scenario. Equation 6 is used to determine the carbon storage in the baseline scenario.

Equation 4: GHG Benefit from Pest Management Activities

$$GHG_{PM} = GHG_{PMP} - GHG_{PMB}$$

Where,			Units
GHG_{PM}	=	GHG benefit of pest management activities	MT CO$_2$e
GHG_{PMP}	=	On-site carbon storage and project emissions in pest management project scenario (from Equation 5)	MT CO$_2$e
GHG_{PMB}	=	On-site carbon storage in pest management baseline scenario (from Equation 6)	MT CO$_2$e

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Equation 5: On-Site Carbon Storage and Project Emissions in Pest Management Project Scenario

$$GHG_{PMP} = \left[\left(CT_{PMNT} + CI_{PMNT} \right) \times \left(1 - R_{PMP} \right) - CR_{PMP} \right] \times 3.67 - BR_{PMP} \times 0.06$$

Where,			Units
GHG_{PMP}	=	On-site carbon storage and project emissions in pest management project scenario	MT CO$_2$e
CT_{PMNT}	=	Carbon within the treatment boundary at the end of the project without disturbance or pest management treatment	MT C
CI_{PMNT}	=	Carbon within the impact boundary at the end of the project without disturbance or pest management treatment	MT C
R_{PMP}	=	Percentage of treatment and impact boundaries at risk with pest management treatment	%
CR_{PMP}	=	Carbon removed as part of pest management treatment	MT C
3.67	=	Conversion factor from C to CO$_2$e	CO$_2$e/C
BR_{PMP}	=	Biomass removed via mechanical treatments	Bone dry tons
0.06	=	Mobile combustion emission factor for biomass removal in pest management project scenario	MT CO$_2$e/ bone dry ton

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Equation 6: On-Site Carbon Storage in Pest Management Baseline Scenario

$$GHG_{PMB} = \left(SLT_{PMNT} + SLI_{PMNT} \right) \times \left(1 - R_{PMB} \right) \times 3.67$$

Where,			Units
GHG_{PMB}	=	On-site carbon storage in pest management baseline scenario	MT CO$_2$e
SLT_{PMNT}	=	Standing live tree carbon within the treatment boundary at the end of the project without disturbance or pest management treatment	MT C
SLI_{PMNT}	=	Standing live tree carbon within the impact boundary at the end of the project without disturbance or pest management treatment	MT C
R_{PMB}	=	Percentage of treatment and impact boundaries at risk without pest management treatment.	%
3.67	=	Conversion factor from C to CO$_2$e	CO$_2$e/C

C. GHG Benefit from Fuels Reduction Activities

The GHG benefit from fuels reduction activities is calculated as the difference between the baseline and project scenarios using Equation 7. Equation 8 is used to determine the carbon storage and project emissions in the project scenario. Equation 9 is used to determine the carbon storage in the baseline scenario.

Equation 7: GHG Benefit from Fuels Reduction Activities

$$GHG_{FR} = GHG_{FRP} - GHG_{FRB}$$

Where,			Units
GHG_{FR}	=	GHG benefit of fuels reduction activities	MT CO$_2$e
GHG_{FRP}	=	On-site carbon storage and project emissions in fuels reduction project scenario (from Equation 8)	MT CO$_2$e
GHG_{FRB}	=	On-site carbon storage in fuels reduction baseline scenario (from Equation 9)	MT CO$_2$e

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Equation 8: On-Site Carbon Storage and Project Emissions in Fuels Reduction Project Scenario

$$GHG_{FRP} = [CTNF_{FRP} + CINF_{FR} - (1 - (1 - APFO_{FR})^{EP}) \times (CTNF_{FRP} + CINF_{FR} - (CTNF_{FRP} - (CTNF_{FRP} - CTWF_{FRP}) \times (CBPT_P/CBPT_B)) - (CINF_{FR} - (CINF_{FR} - CIWF_{FRB}) \times (CBPI_P/CBPI_B) \times (1 - (IFL_B - IFL_P))))] \times 3.67 - BR_{FRP} \times 0.06$$

Where,   <u>Units</u>

GHG_{FRP}	=	On-site carbon storage and project emissions in fuels reduction project scenario	MT CO_2e
$CTNF_{FRP}$	=	Carbon within the treatment boundary at the end of the project with fuels reduction treatment but without fire disturbance (from FVS)	MT C
$CINF_{FR}$	=	Carbon within the impact boundary at the end of the project without fire disturbance (from FVS) (optional)	MT C
$APFO_{FR}$	=	Annual probability of fire occurrence within the treatment and impact boundaries (mean probability from FRAP Fire Probability and Carbon Accounting map tool)	%
EP	=	Effective period for fuels reduction treatment (maximum 25 years)	Years
$CTWF_{FRP}$	=	Carbon within the treatment boundary at the end of the project with fuels reduction treatment and with fire disturbance (from FVS)	MT C
$CIWF_{FRB}$	=	Carbon within the impact boundary at the end of the project without fuels reduction treatment but with fire disturbance (from FVS and IFTDSS) (optional)	MT C
IFL_B	=	Proportion of impact boundary likely to burn at high severity without fuels reduction treatment (optional)	%
IFL_P	=	Proportion of impact boundary likely to burn at high severity with fuels reduction treatment (optional)	%
$CBPT_B$	=	Conditional burn probability without fuels reduction treatment for the portion of the treatment area likely to burn at high severity in the baseline scenario (without fuels reduction treatment) (optional)	%
$CBPT_P$	=	Conditional burn probability in the project scenario (with fuels reduction treatment) for the portion of the treatment area likely to burn at high severity in the baseline scenario (without fuels reduction treatment) (Optional)	%
$CBPI_B$	=	Conditional burn probability without fuels reduction treatment for the portion of the impact area likely to burn at high severity in the baseline scenario (without fuels reduction treatment) (optional)	%
$CBPI_P$	=	Conditional burn probability with fuels reduction treatment for the portion of the impact area likely to burn at high severity in the baseline scenario (without fuels reduction treatment) (optional)	%
3.67	=	Conversion factor from C to CO_2e	CO_2e/C
BR_{FRP}	=	Biomass removed via mechanical treatments	Bone dry tons
0.06	=	Mobile combustion emission factor for biomass removal in fuels reduction project scenario	MT CO_2e/ bone dry ton

Equation 9: On-Site Carbon Storage in Fuels Reduction Baseline Scenario

$$GHG_{FRB} = [CTNF_{FRB} + CINF_{FR} - (1 - (1 - APFO_{FR})^{EP}) \times (CTNF_{FRB} + CINF_{FR} - CTWF_{FRB} - CIWF_{FRB})] \times 3.67$$

Where,			Units
GHG_{FRB}	=	On-site carbon storage in fuels reduction baseline scenario	MT CO$_2$e
$CTNF_{FRB}$	=	Carbon within the treatment boundary at the end of the project without fuels reduction treatment and without fire disturbance (from FVS)	MT C
$CINF_{FR}$	=	Carbon within the impact boundary at the end of the project without fire disturbance (from FVS) (optional)	MT C
$CTWF_{FRB}$	=	Carbon within the treatment boundary at the end of the project without fuels reduction treatment but with fire disturbance (from FVS and FFE-FVS)	MT C
$CIWF_{FRB}$	=	Carbon within the impact boundary at the end of the project without fuels reduction treatment but with fire disturbance (from FVS and IFTDSS) (optional)	MT C
$APFO_{FR}$	=	Annual probability of fire occurrence within the treatment and impact boundaries (mean probability from FRAP Fire Probability for Carbon Accounting map tool)	%
EP	=	Effective period for fuels reduction treatment (maximum 25 years)	Years
3.67	=	Conversion factor from C to CO$_2$e	CO$_2$e/C

D.   GHG Benefit from Avoided Conversion Easement Activities

The GHG benefit from avoided conversion easement activities is calculated as the difference between the baseline and project scenarios using Equation 10. Equation 11 is used to determine the on-site carbon storage in the project scenario. Equation 12 is used to determine the on-site carbon storage in the baseline scenario. Note: If biomass will be removed and utilized in the project scenario, or would be in the baseline scenario, the net GHG benefit from utilization is calculated using Equations 13-17.

Equation 10: GHG Benefit from Avoided Conversion Easement Activities

$$GHG_{AC} = GHG_{ACP} - GHG_{ACB}$$

Where,			*Units*
GHG_{AC}	=	GHG benefit of avoided conversion easement activities	MT CO_2e
GHG_{ACP}	=	On-site carbon storage in avoided conversion easement project scenario (from Equation 11)	MT CO_2e
GHG_{ACB}	=	On-site carbon storage in avoided conversion easement baseline scenario (from Equation 12)	MT CO_2e

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Equation 11: On-Site Carbon Storage in Avoided Conversion Easement Project Scenario

$$GHG_{ACP} = C_{ACP} \times 3.67$$

Where,			*Units*
GHG_{ACP}	=	On-site carbon storage and project emissions in avoided conversion easement project scenario	MT CO_2e
C_{ACP}	=	Standing live and dead tree carbon within the treatment boundary at the end of the project with the conservation easement	MT C
3.67	=	Conversion factor from C to CO_2e	CO_2e/C

Equation 12: On-Site Carbon Storage in Avoided Conversion Easement Baseline Scenario

$$GHG_{ACB} = C_{ACP} \times (100\% - CI_{ACB}) \times 3.67$$

Where,			*Units*
GHG_{ACB}	=	On-site carbon storage in forest conservation baseline scenario	MT CO_2e
C_{ACP}	=	Standing live and dead tree carbon within the treatment boundary at the end of the project with the conservation easement	MT C
CI_{ACB}	=	Conversion impact within the treatment boundary (based on type of conversion threat)	%
3.67	=	Conversion factor from C to CO_2e	CO_2e/C

E.   GHG Benefit from Forest Management Easement Activities

The GHG benefit from forest management easement activities is calculated as the difference between the baseline and project scenarios using Equation 13. Equation 14 is used to determine the on-site carbon storage in the project scenario. Equation 15 is used to determine the on-site carbon storage in the baseline scenario. Note: If biomass will be removed and utilized in the project scenario, or would be in the baseline scenario, the net GHG benefit from utilization is calculated using Equations 16-20.

Equation 13: GHG Benefit from Forest Management Easement Activities

$$GHG_{FM} = GHG_{FMP} - GHG_{FMB}$$

Where,   <u>Units</u>

			Units
GHG_{FM}	=	GHG benefit of forest management easement activities	MT CO_2e
GHG_{FMP}	=	On-site carbon storage in forest management easement project scenario (from Equation 14)	MT CO_2e
GHG_{FMB}	=	On-site carbon storage in forest management easement baseline scenario (from Equation 15)	MT CO_2e

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Equation 14: On-Site Carbon Storage in Forest Management Easement Project Scenario

$$GHG_{FMP} = C_{FMP} \times 3.67$$

Where, <u>Units</u>

			Units
GHG_{FMP}	=	On-site carbon storage and project emissions in forest management easement project scenario	MT CO_2e
C_{FMP}	=	Standing live and dead tree carbon within the treatment boundary at the end of the project with the conservation easement (from FVS)	MT C
3.67	=	Conversion factor from C to CO_2e	CO_2e/C

Equation 15: On-Site Carbon Storage in Forest Management Easement Baseline Scenario

$$GHG_{FMB} = C_{FMB} \times 3.67$$

Where, <u>Units</u>

			Units
GHG_{FMB}	=	On-site carbon storage in forest management easement baseline scenario	MT CO_2e
C_{FMB}	=	Standing live and dead tree carbon within the treatment boundary at the end of the project without the conservation easement (from FVS)	MT C
3.67	=	Conversion factor from C to CO_2e	CO_2e/C

F.   GHG Benefit from Biomass Utilization Activities

Biomass may be removed and utilized for wood products or electricity generation as part of the project.[6] The GHG benefit from biomass utilization activities is calculated as the sum of the benefits of activities that result in carbon being stored long-term in wood products, the displacement of fossil fuel-based energy with biomass energy, and avoidance of biomass disposal emissions using Equation 16.

Equation 16: GHG Benefit from Biomass Utilization Activities

$$GHG_{BU} = GHG_{WP} + GHG_{EG} + GHG_{AE}$$

Where,				Units
GHG_{BU}	=	GHG benefit of biomass utilization activities		MT CO$_2$e
GHG_{WP}	=	GHG benefit from utilizing biomass for wood products (from Equation 18)		MT CO$_2$e
GHG_{EG}	=	GHG benefit from utilizing biomass for electricity generation (from Equation 19)		MT CO$_2$e
GHG_{AE}	=	GHG benefit from avoided biomass disposal emissions (only applicable to biomass utilization activities for biomass *not* removed by other GGRF funded project activities; i.e., biomass that would be removed in the absence of the project) (from Equation 20)		MT CO$_2$e

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The GHG benefit from carbon stored long-term in wood products is calculated based on the net quantity of biomass utilized for wood products, mill efficiency, and the carbon storage factor of the wood products generated. Equation 17 is used to determine the net amount of carbon transferred to wood products as a result of project activities. Projects may use the actual efficiency from the mill where trees will be delivered, supported with documentation, or the appropriate default mill efficiency provided in Table 2. If trees will be delivered to more than one mill with different efficiencies, applicants may provide a weighted mill efficiency. After determining the carbon transferred to wood products, Equation 18 is used to determine the net amount of carbon stored long term in wood products as a result of project activities. To do this, determine the percentage of removed biomass that will go into each wood product class category. If 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.

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[6] Most project activities are not expected to impact long-term biomass removal and utilization over the 50-80 year project life and it is assumed to be equal in the baseline and project scenarios for all project types except avoided conversion easements, in which land that would be converted continues to operate as a working forest, and forest management easements, which by definition involve a change in forest management practices. Biomass that would be removed and utilized in the project baseline scenario (conversion or conventional management) and biomass that would be removed and utilized in the project scenario are therefore included in the biomass utilization calculations.

Equation 17: Carbon Transferred to Wood Products

$$C_{WP} = (BWP_P - BWP_{FCB} + BWP_{FCP}) \times 0.5 \times ME$$

Where,				Units
C_{WP}	=	Carbon transferred to wood products		MT C
BWP_P	=	Biomass to be removed from the project area (with and without GGRF funding) and delivered to a mill to be utilized for wood products in the project scenario		Bone dry tons (BDT)
BWP_{FCB}	=	Biomass that would be removed from within the treatment boundary and utilized for wood products without the conservation easement (avoided conversion and forest management)		BDT
BWP_{FCP}	=	Biomass that is expected to be removed from within the treatment boundary and utilized for wood products with conservation easement (avoided conversion and forest management)		BDT
0.5	=	Conversion factor from wood to carbon		C/wood
ME	=	Mill efficiency		%

Table 2. Default Mill Efficiency

Hardwood	Softwood
56.8%	67.5%

Equation 18: GHG Benefit of Carbon Stored Long-Term 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$_2$e
C_{WP}	=	Carbon transferred to wood products	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$_2$e	CO$_2$e/C

The GHG benefit from utilizing biomass for electricity generation is calculated as the net quantities of biomass utilized for electricity generation via combustion and gasification, multiplied by a process specific emission reduction factor. Equation 19 is used to determine the net GHG benefit from generating electricity.

Equation 19: GHG Benefit from Utilizing Biomass for Electricity Generation

$$GHG_E = (BEC_P - BEC_{FCB} + BEC_{FCP}) \times 0.18 + (BEG_P - BEG_{FCB} + BEG_{FCP}) \times 0.23$$

Where,   Units

			Units
GHG_E	=	GHG benefit from utilizing biomass for electricity generation	MT CO$_2$e
BEC_P	=	Biomass to be removed from the project area (with and without GGRF funding) and delivered to a biomass facility generating electricity via combustion as part of the project	Bone dry tons (BDT)
BEC_{FCB}	=	Biomass that would be removed from within the forest conservation treatment boundary and utilized for electricity generation via combustion without the conservation easement	BDT
BEC_{FCP}	=	Biomass that is expected to be removed from within the forest conservation treatment boundary and utilized for electricity generation via combustion with the conservation easement	BDT
0.18	=	Emission reduction factor for electricity generation via combustion	MT CO$_2$e/ BDT
BEG_P	=	Biomass to be removed from the project area (with and without GGRF funding) and delivered to a biomass facility generating electricity via gasification as part of the project	BDT
BEG_{FCB}	=	Biomass that would be removed from within the forest conservation treatment boundary and utilized for electricity generation via gasification without the conservation easement	BDT
BEG_{FCP}	=	Biomass that is expected to be removed from within the forest conservation treatment boundary and utilized for electricity generation via gasification with the conservation easement	BDT
0.23	=	Emission reduction factor for electricity generation via gasification	MT CO$_2$e/ BDT

If the project funds the utilization of biomass removed as part of management practices not associated with the project (i.e., the forest treatment was not funded by the GGRF grant but complementary services such as transportation to a biomass facility or mill is funded with GGRF grant money), the project may include the GHG benefit of avoided CH_4 and N_2O emissions[7] from an open pile burn, landfilling, or leaving biomass to decay on-site using Equation 20. No credit is given for avoiding disposal emissions of material that would only require disposal as a result of the project (i.e., biomass removed as part of GGRF-funded forest treatments).

Equation 20: GHG Benefit from Avoided Biomass Disposal Emissions

$$GHG_{AE} = \left[(BDT_{PBB} \times 0.16) \times 0.907185 + (BDT_{LB} \times 0.21) + (BDT_{DB} \times 1.25) \times 0.907185 \right.$$

Where,			Units
GHG_{AE}	=	Avoided emissions from open pile burning, landfilling, or leaving biomass to decay on-site	MT CO_2e
BDT_{PBB}	=	Biomass that would be removed and open pile burned without the project	Bone dry tons (BDT)
0.16	=	Emission factor for open pile burning of removed biomass	Ton CO_2e /BDT
BDT_{LB}	=	Biomass that would be removed and landfilled without the project	BDT
0.21	=	Emission factor for landfilling removed biomass	MT CO_2e /BDT
BDT_{DB}	=	Biomass that would be removed and left to decay on-site without the project	BDT
1.25	=	Emission factor for leaving removed biomass to decay on-site	Ton CO_2e /BDT
0.907185	=	Conversion factor from ton to metric ton	MT/ton

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[7] Biogenic CO_2 emissions are excluded consistent with the CARB GHG inventory accounting methods.

G.   Net GHG Benefit from Project Activities

The net GHG benefit from any project is the sum of the GHG benefit from reforestation, pest management, fuels reduction, forest conservation and biomass utilization activities. Equation 21 is used to determine the net GHG benefit from forest restoration and management projects.

Equation 21: Net GHG Benefit

$$GHG = \left(GHG_R + GHG_{PM} + GHG_{FR} + GHG_{AC} + GHG_{FM} + GHG_{BU} \right)$$

Where,			Units
GHG	=	Net GHG benefit from the project	MT CO$_2$e
GHG$_R$	=	GHG benefit from reforestation activities	MT CO$_2$e
GHG$_{PM}$	=	GHG benefit from pest management activities	MT CO$_2$e
GHG$_{FR}$	=	GHG benefit from fuels reduction activities	MT CO$_2$e
GHG$_{AC}$	=	GHG benefit from avoided conversion easement activities	MT CO$_2$e
GHG$_{FM}$	=	GHG benefit from forest management easement activities	MT CO$_2$e
GHG$_{BU}$	=	GHG benefit from biomass utilization activities	MT CO$_2$e

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H.   Renewable Energy Generated

The quantity of renewable energy generated from the project is estimated using Equation 22 based on the amount of woody biomass sent to an energy facility that generates electricity via combustion or gasification.

Equation 22 Renewable Energy from Project Activities

$$kWh = (BEC_P - BEC_{FCB} + BEC_{FCP}) \times 0.90 \times 1000 + (BEG_P - BEG_{FCB} + BEG_{FCP}) \times 1.11 \times 1000$$

Where,				Units
BEC_P	=	Biomass to be removed from the project area (with and without GGRF funding) and delivered to a biomass facility generating electricity via combustion as part of the project		Bone dry tons (BDT)
BEC_{FCB}	=	Biomass that would be removed from within the forest conservation treatment boundary and utilized for electricity generation via combustion without the conservation easement		BDT
BEC_{FCP}	=	Biomass that is expected to be removed from within the forest conservation treatment boundary and utilized for electricity generation via combustion with the conservation easement		BDT
0.90	=	Electricity generated by biomass energy plants in California per ton of biomass waste combustion		MWh/BDT
1.11	=	Electricity generated by biomass energy plants in California per ton of biomass waste gasification		MWh/BDT
1000	=	Conversion from MWh to kWh		kWh/MWh
BEG_P	=	Biomass to be removed from the project area (with and without GGRF funding) and delivered to a biomass facility generating electricity via gasification as part of the project		BDT
BEG_{FCB}	=	Biomass that would be removed from within the forest conservation treatment boundary and utilized for electricity generation via gasification without the conservation easement		BDT
BEG_{FCP}	=	Biomass that is expected to be removed from within the forest conservation treatment boundary and utilized for electricity generation via gasification with the conservation easement		BDT

Section C. References

The following references were used in the development of this Quantification Methodology, the Forest Restoration and Management Benefits Calculator Tool, and the Forest Restoration and Management Benefits Calculator Tool User Guide.

California Air Resources Board. (2009). *Detailed California-Modified GREET Pathway for Cellulosic Ethanol from Forest Waste*.

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. (2014). *Compliance Offset Protocol U.S. Forest Projects*.
https://www.arb.ca.gov/regact/2014/capandtrade14/ctusforestprojectsprotocol.pdf.

California Air Resources Board. (2017). *Method for Estimating Greenhouse Gas Emission Reductions from Diversion of Organic Waste from Landfills to Compost Facilities*. Link to compost emissions reduction factor document.

California Air Resources Board and CalRecycle. (2013). *Biomass Conversion*.

Mann ML, Batllori E, Moritz MA, Waller EK, Berck P, Flint AL, et al. (2016) Incorporating Anthropogenic Influences into Fire Probability Models: Effects of Human Activity and Climate Change on Fire Activity in California. *PLoS ONE* 11 (4): e0153589. doi:10.1371/journal.pone.0153589.
http://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0153589&type=printable

Placer County Air Pollution Control District. (2013). *Biomass Waste for Energy Project Reporting Protocol, Version 6.3*.
https://www.placerair.org/DocumentCenter/View/2115/Biomass-Waste-For-Energy-Project-Protocol-PDF.

Scott and Burgan. (2005). *Standard Fire Behavior Fuel Models: A Comprehensive Set for Use with Rothermel's Surface Fire Spread Model*.
http://www.fs.fed.us/rm/pubs/rmrs_gtr153.pdf.

Sonne, E. (2006). Greenhouse Gas Emissions from Forestry Operations: A Life Cycle Assessment. *Journal of Environmental Quality*, 35, 1439-1450.
https://dl.sciencesocieties.org/publications/jeq/pdfs/35/4/1439

Sonoma County Water Agency, prepared by W. David Featherman. (2013). *Feasibility of Using Residual Woody Biomass to Generate Electricity for Sonoma County*.
https://evogov.s3.amazonaws.com/185/media/182331.pdf.

United States Forest Service. (2015). *Essential FVS: A user's guide to the Forest Vegetation Simulator*. http://www.fs.fed.us/fmsc/ftp/fvs/docs/gtr/EssentialFVS.pdf.

Unites States Forest Service. *Forest Vegetation Simulator and Fire & Fuels Extension*. https://www.fs.fed.us/fvs/.

United States Forest Service Fire and Environmental Research Applications Team. *Consume*. Link to Consume fire model.

United States Forest Service Fire and Environmental Research Applications Team. *First Order Fire Effects Model*. http://www.firelab.org/project/fofem.

United States Forest Service Forest Health Technology Enterprise Team. (2012). *National Insect and Disease Risk Map*. National Insect and Disease Risk Map .

United States Forest Service Northern Research Station and National Council for Air and Stream Improvement. (2016). *Carbon On Line Estimator*. carbon on line estimator homepage.

United States Forest Service Rocky Mountain Research Station, Fire, Fuel, and Smoke Science Program. (2000) *FireFamilyPlus*. https://www.firelab.org/project/firefamilyplus

United States Forest Service Rocky Mountain Research Station, Fire, Fuel, and Smoke Science Program. (2006) *FlamMap*. https://www.firelab.org/project/flammap.

United States Forest Service and United States Department of the Interior. *LANDFIRE*. https://www.landfire.gov/

United States Forest Service and University of California Cooperative Extension (1991). 1979. *Forest survey site classes and their equivalents in local site classification systems*. USFS-RS- TM. 8-10-79. Revised UCCE 12-11-91.

National Interagency Fire Center. (2016). Remote automated weather station data. https://raws.nifc.gov/.