# Memorandum

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| **Subject:** | **2021 CAPCOA Handbook Update: Develop Process and Summaries for up to 10 Quantification Measures (Final Draft)** |

# Introduction

ICF has conducted an initial review of 10 Greenhouse Gas (GHG) reduction measures for inclusion in the California Air Pollution Control Officers Association (CAPCOA) Handbook (Handbook) and made a quantification determination for each measure. The list of measures, sourced by Sacramento Metropolitan Air Quality Management District (SMAQMD) based on input received from the Sacramento-Roseville Combined Statistical Area Priority Climate Action Plan partner jurisdictions, were classified into three categories: quantifiable (six measures), likely quantifiable (three measures), and not quantifiable (one measure).

With the initial review of the 10 GHG reduction measures completed, ICF has engaged in the next task of this project, which involves the development of quantification methodologies for the measures that have been identified as quantifiable or likely quantifiable. This memorandum presents the methods for quantifying GHG reductions, where available, for the quantifiable and likely quantifiable measures. The measures are grouped into the following five sectors: Transportation, Energy, Solid Waste, Natural and Working Lands, and Miscellaneous. Methods were only developed for those measures with literature to defensibly support emissions quantification. Examples of credible sources consulted for this memorandum include government agency–sponsored studies, peer-reviewed scientific literature, case studies, government-approved modeling software, and widely adopted protocols.

This memorandum includes the following subsections for each measure, which generally match the headers in the measure factsheets from the Handbook.

- **Measure Description**
- **Scale of Application (Locational Context)**
- **GHG Reduction Formula**
- **GHG Calculation Variables**
- **GHG Calculation Caps or Maximums**
- **Example GHG Quantification**
- **Measure Co-Benefits**
- **Sources**

These subsections are explained in detail in Chapter 3 of the Handbook.[1] The factsheets in the Handbook include additional subsections and information that are not included in this memo, such as *Implementation Requirements*, *Cost Considerations*, and *Climate Resilience*. This information will ultimately be presented for the new Handbook measures once the factsheets are developed for the measures.

# Quantifying Greenhouse Gas Emissions Reductions

This section provides important information and context regarding the quantification methods and use of the new GHG reduction measures. Much of this information is included in the Handbook; however, it is included here because of its relevance to the current quantification effort.

The emissions quantification methods in this memorandum are designed to provide GHG estimates using readily available data and user-specified information. As with the Handbook, emission reductions are quantified (1) as a percentage of emissions from a given source or activity, or (2) by calculating the absolute emissions reductions achieved with implementation of the measure.[2]

Quantification methods that provide a percent reduction rely on the underlying assumption that GHG emissions are proportional to the emissions source. For example, emissions reductions achieved by a transportation measure are estimated using the expected percent reduction in vehicle trips or VMT, with a corresponding adjustment to account for the relationship between VMT reduction and vehicle emissions. For these measures, users will need to multiply the reduction percentage by the amount of emissions that would be generated by that source without implementation of the measure to calculate the absolute reductions.[3] Consistent with the Handbook, this memorandum does not include methods for inventorying emissions from specific sources or under various scenarios, such as baseline or existing conditions.

[1] https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=56

[2] When appropriate, some measures refer readers to external tools to quantify GHG reductions.

[3] The reduction percentage is denoted as a positive value when specified in text or in tables as a "reduction," and is denoted as a negative value when calculated in equations.

Quantification methods that calculate absolute reductions estimate the amount of emissions that would be released as a result of the source or activity with implementation of the measure (e.g., the reduction in solid waste GHG emissions achieved from edible food recovery). All GHG reductions are expressed in metric tons (MT) of carbon dioxide equivalents ($CO_2e$), where individual GHGs that would be reduced by a measure are converted to $CO_2e$ by multiplying emissions by their global warming potentials (GWP).[4] GHGs evaluated in this memorandum include $CO_2$, methane ($CH_4$), nitrous oxide ($N_2O$), and refrigerant gases.

As in the Handbook, the quantification methods in this memorandum generally include those reductions over which a user can exercise direct control. The quantification methods do not include analysis of lifecycle emissions, except for the biomass energy and food recovery measures. A lifecycle analysis attempts to identify and quantify the GHG emissions associated with the energy and materials used at all stages of the product's life, from the gathering of raw materials through the growing or fabrication, distribution, use, and disposal at the end of the product's useful life. Because of the difficulties in quantifying lifecycle emissions, lifecycle considerations are only included in the quantitative methods for those measures that cannot be quantified without a lifecycle analysis.

Consistent with the Handbook, geographic levels considered in this memorandum include **Project/Site** (the scale of a parcel, employer, or development project.) and **Plan/Community** (the scale of a neighborhood [e.g., specific plan], corridor, or entire municipality [e.g., city- or county-level]). The transportation measures can be quantified at either the Project/Site scale or the Plan/Community scale, but not both. Some non-transportation measures can be quantified at both the Project/Site scale and the Plan/Community scale.

# Co-Benefits

Co-benefits are additional benefits that are associated with emissions reduction measures and have become increasingly prevalent in justifying funding, planning, and implementation of emission reduction measures. The types of co-benefits corresponding to the new reduction measures are consistent with those evaluated in the Handbook and are summarized in Table 1. Only those co-benefits with literature and methodologies to support accurate and reliable quantification are presented in this memorandum. Where quantification is not appropriate, co-benefits that may be achieved are stated for each measure.

**Table 1. Co-Benefits of New Reduction Measures**

| Co-Benefit Category | Scope of Benefit |
|---|---|
| Improved air quality | Criteria pollutant reductions |
| Energy and fuel savings | Electricity, natural gas, refrigerant, propane, gasoline, or diesel reductions |
| Vehicle miles traveled (VMT) reductions | Reductions in vehicle miles traveled |
| Water conservation | Water use reductions |
| Enhanced pedestrian or traffic safety | Reduced collisions; pedestrian/bicyclist safety |
| Improved public heath | Toxic air contaminant reductions (including exposure); increased physical activity; improved public safety |

[4] GWP values from the *Intergovernmental Panel on Climate Change's Fourth Assessment Report* are used, consistent with the Handbook and statewide GHG emissions reporting protocol.

| Co-Benefit Category | Scope of Benefit |
|---|---|
| Improved ecosystem health | Improved biological diversity and soil and water quality |
| Enhanced energy security | Systemwide load reduction; local energy generation, levelling out peaks |
| Enhanced food security | Stability of food systems; improved household access to food |
| Social equity | Address existing social inequities (e.g., housing/anti-displacement, community engagement, availability of disposable income) |

While all measures achieve at least one co-benefit, some measures may also yield a *disbenefit*. For example, measures that electrify a fossil-fuel source will lead to improved air quality and fuel savings but *increased* electricity consumption. The potential disbenefits are discussed within the measure quantification methods.

## Other Quantification Considerations

Chapter 3 of the Handbook provides additional considerations regarding measure quantification that are also relevant to the new reduction measures. These topics include quantification accuracy and reliability; combining measure reductions; combining sector reductions; and limitations and uncertainty. Because they are discussed in the Handbook, this memorandum does not include discussion of these topics. However, the content written in the Handbook (e.g., the accuracy of the quantification methods, how should measure or sector reductions be combined), applies to the new measures.

# Measure Quantification Details by Sector

## Transportation

The transportation sector is a critically important part of the Handbook and is the dominant sector in terms of numbers of measures. Continuing with that trend, half of the new Handbook measures are comprised of transportation measures, which speaks to the demand to do even more to reduce transportation-related emissions. The measures included in this memorandum have some overlap with measures in the Handbook but introduce a different aspect of measure implementation than was presented in the Handbook.

In general, transportation emissions can be reduced by improving the emissions profile of the vehicle fleet, or by reducing VMT. Transportation emission reductions in this memorandum are determined by evaluating the elasticity of a measure relative to the amount of VMT that may be reduced by the measure. The measures presented in this memorandum lead to mode shifts from single occupancy vehicles to shared (e.g., transit) or active modes of transportation (e.g., bicycle, walking).

# T-55. Infill Development

## Description

This measure applies to infill housing development programs that allow residents to live closer to downtown areas where there is greater access to jobs and activities. To ensure that the development would only proceed with implementation of this measure, the applicable projects would have to be commercial or industrial lots that are rezoned as high-density residential or mixed-use. GHG reductions from this measure cannot be credited unless the project site is currently a commercial or industrial lot that is being rezoned into either high-density residential or mixed-use. The decision to locate the project site closer to a downtown area relative to an area farther out would lead to lower GHG emissions, resulting from lower VMT for populations in high-density residential or mixed-use developments compared to the region as a whole. An example implementation of this measure is Sacramento Area Council of Government's Green Means Go program (SACOG 2021a; SACOG 2021b).

## Scale of Application (Locational Context)

Project/Site (urban, suburban)

## GHG Reduction Formula

$$A = \frac{\boldsymbol{B - C}}{\boldsymbol{C}} \times D$$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Percent reduction in GHG emissions from project VMT in study area | 0–30.0 | % | calculated |
| User Inputs | | | | |
| **B** | Distance to downtown for proposed project | [ ] | miles | user input |
| **C** | Distance to downtown of typical development | [ ] | miles | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| D | Elasticity of VMT with respect to distance to downtown | -0.22 | unitless | Ewing et al. 2010; Stevens 2016 |

Further explanation of key variables:

- ($B$) – For poly-centric metros such as the San Francisco-Oakland-Berkeley metropolitan statistical area (MSA), the downtown area used to measure the distance needs to represent the closest of the relevant polycentric cities. For example, for a development in San Leandro, downtown Oakland would be the relevant downtown.
- ($C$) – This variable needs to be estimated for each region or metropolitan planning organization (MPO) where the measure will be applied because it differs greatly based on geographic context. Using geographic information system (GIS) tools, this distance can be measured using the Census Centers of Population data for each block group to estimate the average distance to the appropriate downtown within a region weighted by population. For example, applying this

technique to the San Francisco-Oakland-Berkeley MSA for the dual centroids of Oakland and San Francisco yields a population-weighted average distance of 21.6 kilometers or 13.4 miles.

- ($D$) – An analysis of three studies where disaggregate travel data were used found that a 0.22 percent decrease in VMT occurs for every 1 percent decrease in distance to downtown (Ewing et al. 2010).

## GHG Calculation Caps or Maximums

### Measure Maximum

($A_{max}$) – The percent reduction in GHG emissions ($A$) is capped at 30 percent. The purpose for the 30 percent cap is to limit the influence of any single built environmental factor (such as density). Projects that implement multiple land use strategies (e.g., density, design, diversity) will show more of a reduction than relying on improvements from a single built environment factor.

### Subsector Maximum

$\left(\sum A_{max_{T-1\ through\ T-4}} \leq 65\%\right)$ – This measure is in the Land Use subsector. This subcategory includes Measures T-1 through T-4 from the Handbook. The VMT reduction from the combined implementation of all measures within this subsector is capped at 65 percent. This measure could not be used in conjunction with T-1. Increase Residential Density or T-3. Transit-Oriented Development due to correlation between distance to downtown and the other measures.

## Example GHG Reduction Quantification

The user reduces VMT by rezoning areas near the downtown area to allow for a new mixed-use development. Areas that were undeveloped but already zoned as mixed-use can still achieve reductions, but such reductions can only be attributed to the developer and not to an MPO or City. This requirement ensures the benefits are not counted for projects that could have happened without the rezoning process. In this example, the projects would be located 5 miles from downtown ($B$) in a metro area where the population-weighted average distance to downtown is 25 miles ($C$). This would reduce GHG emissions from the projects' VMT by 17.6 percent.

$$\text{A} = \frac{\mathbf{5\ mi - 25\ mi}}{\mathbf{25\ mi}} \times -0.22 = 17.6\%$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, VMT reductions, enhanced pedestrian or traffic safety, improved public health and enhanced energy security. This section defines the methods for quantifying improved air quality, energy and fuel savings, and VMT reductions.

### Improved Air Quality

The criteria pollutants CO, $NO_2$, $SO_2$, and particulate matter (PM) are local pollutants that can potentially affect populations near the emissions source. Accordingly, projects that reduce localized criteria pollutant emissions can improve ambient air quality. The percent reduction in GHG emissions ($A$) achieved by the measure would be the same as the percent reduction in localized criteria pollutant emissions. This measure would also reduce emissions of ozone precursors (oxides of nitrogen [NOx] and reactive organic gases [ROG]), which are regional pollutants. While the percent reduction in NOx emissions would be the same as the percent reduction in GHG emissions, the percent reduction in ROG would not be the same. The percent reduction in GHG emissions must be multiplied by an adjustment factor of 87 percent to account for the evaporative ROG emissions that would not be reduced by this measure. See *Adjusting VMT Reductions to Emission Reductions* in the Handbook for further discussion.[5]

#### Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

#### VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

### Sources

Ewing, R., and R. Cervero. 2010. Travel and the Built Environment: A Meta-Analysis. *Journal of the American Planning Association* 76(3):265–294. Available: https://doi.org/10.1080/01944361003766766. Accessed: December 2023.

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Sacramento Area Council of Governments (SACOG). 2021b. *Criteria for Establishing Green Means Go "Green Zones"*. Available: https://www.sacog.org/funding/regional-funding-programs/green-means-go/establishing-green-zones. Accessed: August 2023.

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## T-56. Active Modes of Transportation for Youth

### Description

Trips to school and extracurricular activities represent most of the everyday travel taken by youth. Thus, ensuring that children can use active transportation whenever possible can serve to reduce VMT and allow them to get the necessary exercise to live healthy lives. To support these efforts, California was the first state in the country to develop a funding program for Safe Routes to Schools (SR2S). This program provides federal funding for new sidewalks, bike lanes, off-street pathways, and street crossings to help children use active modes of transportation to get to school. SR2S projects provide infrastructure that makes it safer and more convenient for kids to get to school and bring health benefits to children in addition to reductions in VMT from mode-shifts away from private vehicle trips. This measure is a blanket measure that can cover projects related to all forms of active transport among youth. Specific projects that are implemented need not be funded by SR2S

[5] https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=80

or be located at a school; however, one advantage of the program is the requirement for student travel surveys, which provide critical before and after project data, to quantify the effects of the program. It is assumed that driving trips are the only trips that lead to emissions. Trips to school by bike, bus, or on foot are assumed to be zero emission, and thus any mode shift away from private auto trips can be assumed to be a direct reduction in emissions.

## Scale of Application (Locational Context)

Project/Site (urban, suburban)

## GHG Reduction Formula

$$A = C \times F \times \frac{D - \boldsymbol{B}}{G \times E \times \ (1 - C) + C \times D \times F}$$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Percent reduction in GHG emissions from vehicle travel among students within walking/biking distance | 0–22.2 | % | calculated |
| User Inputs | | | | |
| **B** | Known or estimated percent of students within 2 miles who are driven to school after project implementation | 0–100 | % | Use survey data – see tools from SR2S |
| Constants, Assumptions, and Available Defaults | | | | |
| C | Percent of students living within 2 miles of the school | 62 | % | SR2S Partnership 2013 |
| D | Percent of students living within 2 miles who are driven to school before measure implementation | 51 | % | SR2S Partnership 2013 |
| E | Percent of students living more than 2 miles who are driven to school | 66 | % | FHWA 2023 |
| F | Average driving distance for students who could walk or bike to school | 2 | miles | Assumption |
| G | Average driving distance for students who cannot walk or bike to school (> 2 mi) | 8.66 | miles | FHWA 2023 |

Further explanation of key variables:

- ($B$) – This is the percentage of students who could walk or bike to school who are driven to school after the project implementation. An informed estimate could be used if calculating reductions for a future project; however, survey data after the fact will provide the most accurate result.
- ($C$) – It is estimated in SR2S Partnership's 2013 report that 62 percent of students live within 2 miles of their school. The assumption that students are not willing to bike or walk longer than 2 miles is a simplification that makes it easier to exclude students who could not have benefited from infrastructure or programming that encourages walking and biking to school. If survey

data are available, users should select a value that is representative of the school, school district, or youth center where the project is being implemented.

- ($D$) – This represents the percentage of students who live within 2 miles of school but are driven to school, nonetheless. This value is from the statewide average, but a local-specific value should be used if that is available for the school or school district.
- ($E$) – This represents the percentage of students outside of the 2-mile radius who are driven to school. This value is derived from 2022 National Household Travel Survey (NHTS) data, but a local value should be used instead if it is available.
- ($F$) – This value represents the average driving distance for students who could walk or bike to school. This is based on the earlier assertion that students would not be willing to travel more than 2 miles by bike or on foot to school. If survey data are available, users should select a value that is representative of the school, school district, or youth center where the project is being implemented.
- ($G$) – Using 2022 NHTS data, it is estimated that the average driving distance for students who cannot walk or bike to school is 8.66 miles. If more local data is available for the school area, use that value instead.

## GHG Calculation Caps or Maximums

### Measure Maximum

($A_{max}$) – The percent reduction in GHG emissions ($A$) is capped at 22.2 percent. The benefits are unlikely to be this high because this level assumes that all students who could walk or bike to school start doing so.

### Subsector Maximum

( $\sum A_{max\ T\text{-}56\ \&\ T\text{-}40} \leq 72\%$) – This measure is in the School Programs subsector. This subcategory includes Measures T-56 and T-40 at the Project/Site scale of application. The school trip VMT reduction from the combined implementation of all measures within this subsector is capped at 72 percent.

## Example GHG Reduction Quantification

A school installs a new raised pedestrian crossing in combination with an outreach program that brings children to school as part of a walking school bus. After this program is implemented, the percentage of students within 2 miles of school who are driven to school drops to 20 percent ($B$). This would lead to a reduction in GHG emissions from school trips of 13.7 percent.

$$\mathrm{A} = 62\% \times 2\ mi \times \frac{51\% - \mathbf{20}\%}{8.66\ mi \times 66\%\ (1 - 62\%) + 62\% \times 51\% \times 2\ mi} = 13.7\%$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, VMT reductions, enhanced pedestrian or traffic safety, improved public health, and social equity. This section defines the methods for quantifying improved air quality, energy and fuel savings, and VMT reductions.

#### Improved Air Quality

The criteria pollutants CO, $NO_2$, $SO_2$, and PM are considered local pollutants that can be deposited and potentially affect populations near the emissions source. Accordingly, projects that reduce localized criteria pollutant emissions can improve ambient air quality. The percent reduction in GHG emissions ($A$) achieved by the measure would be the same as the percent reduction in localized criteria pollutant emissions. This measure would also reduce emissions of ozone precursors (NOx and ROG), which are regional pollutants. While the percent reduction in Nox emissions would be the same as the percent reduction in GHG emissions, the percent reduction in ROG would not. The percent reduction in GHG emissions must be multiplied by an adjustment factor of 87 percent to account for the evaporative ROG emissions that would not be reduced by this measure. See *Adjusting VMT Reductions to Emission Reductions* in the Handbook for further discussion.

#### Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

#### VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

### Sources

California Air Resources Board (CARB). 2023. *Clean Mobility Benefits Quantification Methodology*. Available: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/carb_clean-mobility-qm_draft_july2023.pdf. Accessed: August 2023.

Federal Highway Administration (FWHA). 2023. *2022 National Household Travel Survey*. Available: https://nhts.ornl.gov/. Accessed: December 2023.

Safe Routes to School National Partnership (SR2S Partnership). 2013. *Travel to School in California: Key Findings from the National Household Travel Survey.* Available: https://saferoutespartnership.org/sites/default/files/pdf/Travel%20to%20School%20in%20California%20Policy%20Brief%20PAGES.pdf. Accessed: December 2023.

## T-40. Establish a School Bus Program

### Description

Busing provides a practical way to transport students to school while also offering reductions in GHG emissions when there is high enough ridership. When districts establish busing programs, they directly replace automobile trips to take students to and from school. Because traditional diesel school buses take a much longer tour than a direct drive to school, and because their vehicles have much higher emissions per mile than a typical light duty vehicle, buses need to transport a high number of students to make up for the emissions caused by the bus. The circumstances change, however, with the introduction of electric buses, where even a very small capacity bus of five students leads to emission reductions relative to the average passenger vehicle. This measure estimates the emission benefit or disbenefit associated with establishing or expanding a school bus program.

## Scale of Application (Locational Context)

Project/Site (urban, suburban)

## GHG Reduction Formula

$$\mathrm{A} = \frac{\boldsymbol{B} \times \mathbf{C} \times \left(\frac{\mathrm{G}}{D} - \frac{F \times H}{\mathrm{E}}\right)}{\frac{\mathrm{G}}{\mathrm{D}}}$$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Percent reduction in GHG emissions from vehicle travel among students | 0–72 | % | calculated |
| User Inputs | | | | |
| **B** | Percent of students across the school who begin riding the bus as a result of the program | 0–100 | % | user input |
| **C** | Percent of students served by bus system (regardless of whether they ride) | 0–100 | % | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| D | Average student occupancy of cars driving to school | 1.58 | students/car | FHWA 2023 |
| E | Average student occupancy of school buses | See Table T-40.1 (Appendix A) | students/bus | Wang et al. 2019 |
| F | Adjustment for ratio of bus touring distance to driving distance | 3.42 | unitless | FHWA 2023; Duran 2013 |
| G | Light duty emission factor | See Table T-30.2 (Handbook) | grams $CO_2e$/mile | CAPCOA 2021 |
| H | School bus emission factor | See Table T-40.2 (Appendix A) | grams $CO_2e$/mile | CARB 2021 |

Further explanation of key variables:

- ($B$) – This is the percentage of students at the school who can ride the bus and who begin riding the bus after the implementation of the program. For a new program, this is equal to the percentage of all students who ride. For a program change, this is equal to the difference in percentage of students who ride before and after the program implementation.
- ($C$) – This is the percentage of students for whom the bus program provides service. If only one neighborhood is served, then this is the percentage of students at the school who live in that neighborhood.
- ($D$) – This constant is from NHTS and represents the average occupancy of school trips taken by car in the Pacific division. NHTS does not consider the driver an occupant if they are dropping someone off; however, students driving themselves to school are included in this occupancy value.

- $(E)$ – This constant represents an estimate of the average occupancy of school buses based on research from Wang et al. 2019.
- $(F)$ – This constant was derived from NHTS data and school bus drive cycle data from Duran 2013. The average school trip taken in a private vehicle is 9.3 miles long in the Pacific Census division, while the average school bus tour is 31.7 miles. Thus, the ratio of bus touring distance to driving distance is 3.42.
- $(G)$ – These light duty emissions factors are used throughout the Handbook and represent the emissions of cars taking students to school. The emission factor for light trucks is most appropriate, because SUVs are the most popular vehicles in California.
- $(H)$ – The school bus emission factor is taken from the most recent version of EMFAC and is used to determine the new emissions from the school buses added by this program. If a different type of vehicle is used for the program (such as a van or other light-duty vehicle), users should select the appropriate emission factor for that vehicle type as found in Table T-30.2 in the Handbook.

## GHG Calculation Caps or Maximums

### Measure Maximum

$(A_{max})$ – The percent reduction in GHG emissions $(A)$ is capped at 72 percent. The benefits are unlikely to be this high; this level assumes that buses have an occupancy of 17.3 students, all buses are electric, and all students ride the bus.

### Subsector Maximum

$(\sum A_{max\ T\text{-}55\ \&\ T\text{-}40} \leq 72\%)$ – This measure is in the School Programs subsector. This subcategory includes Measures T-56 and T-40 at the Project/Site scale of application. The school trip VMT reduction from the combined implementation of all measures within this subsector is capped at 72 percent.

## Example GHG Reduction Quantification

A school district in the San Diego area starts a new busing program that serves all students but only 50 percent (B) of eligible students ride. The buses run on compressed natural gas and the average parent drives their child to school in an SUV. This would lead to a reduction in GHG emissions from school-based trips of 7.3 percent.

$$\mathrm{A} = \frac{\mathbf{50}\% \times \mathbf{100}\% \times \left( \dfrac{416.9\,\frac{\mathrm{g}}{\mathrm{mi}}}{1.58\,\frac{riders}{veh}} - \dfrac{3.42 \times 981\,\frac{g}{mi}}{14.9\,\frac{riders}{veh}} \right)}{\dfrac{416.9\ \mathrm{g/mi}}{1.58\,\frac{\mathrm{riders}}{\mathrm{veh}}}} = 7.3\%$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, VMT reductions, enhanced pedestrian or traffic safety, improved public health, and social equity. This section defines the methods for quantifying improved air quality, energy and fuel savings, and VMT reductions.

### Improved Air Quality

The criteria pollutants CO, $NO_2$, $SO_2$, and PM are considered local pollutants that can be deposited and potentially affect populations near the emissions source. Accordingly, projects that reduce localized criteria pollutant emissions can improve ambient air quality. The percent reduction in GHG emissions ($A$) achieved by the measure would be the same as the percent reduction in localized criteria pollutant emissions. This measure would also reduce emissions of ozone precursors (NOx and ROG), which are regional pollutants. While the percent reduction in NOx emissions would be the same as the percent reduction in GHG emissions, the percent reduction in ROG would not. The percent reduction in GHG emissions must be multiplied by an adjustment factor of 87 percent to account for the evaporative ROG emissions that would not be reduced by this measure. See *Adjusting VMT Reductions to Emission Reductions* in the Handbook for further discussion.

### Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

### VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

## Sources

California Air Pollution Control Officer's Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2.* Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

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Wang, Y., R. Mingo, J. Lutin, W. Zhu, and M. Zhu. 2019. *Developing a Statistically Valid and Practical Method to Compute Bus and Truck Occupancy Data*. Federal Highway Administration. Available: https://www.academia.edu/64325343/Developing_a_Statistically_Valid_%E2%80%8Cand_Practical_Method_to_Compute_Bus_and_Truck_Occupancy_Data. Accessed: December 2023.

## T-34. Provide Bicycle Parking

### Description

This measure requires that projects provide short-term and long-term bicycle parking facilities to meet peak season maximum demand. Parking can be provided in designated areas or added within rights-of-way, such as by replacing car parking spaces with bike parking corrals. Users should ensure that bike parking can be accessed by all, not just project employees or residents. Users are encouraged to review the *Essentials of Bike Parking* from the Association of Pedestrian and Bicycle Professionals (APBP) (APBP 2015). In general, the APBP recommends that short-term bike parking should be close to the entry point of the corresponding land use, be secured to the ground appropriately, and have a sufficient number of parking spaces. Long-term parking requires additional considerations with respect to security, such as constructing parking inside locked rooms or secured enclosures with key-card access.

In the Handbook, there is an identical non-quantified measure (Measure T-34. *Provide Bike Parking*). As concluded previously, this measure is not quantifiable with currently available scientific literature and research. GHG reductions cannot be quantified for the installation of bicycle parking by itself because available scientific literature and research has not shown that bicycle parking alone will reduce VMT.

### Scale of Application (Locational Context)

Project/Site (urban, suburban)

### Sources

Association of Pedestrian and Bicycle Professionals (APBP). 2015. *Essentials of Bike Parking: Selecting and installing bicycle parking that works*. September. Available: https://www.apbp.org/assets/docs/EssentialsofBikeParking_FINA.pdf. Accessed: December 2023.

## T-22-D. Transition Conventional to Electric Bikeshare

### Description

Research in the state of California has found that electric bikeshare programs lead to increased ridership and accessibility over traditional bikes. This makes sense because, with an electric bike, it is easier to climb hills and is more enjoyable and faster for riders to get where they are going, leading to increased utility. This measure estimates the emissions improvement realized by transitioning an existing traditional bikeshare program to an electric bikeshare program using a methodology that aligns with Measure T-22-A, *Implement Pedal (Non-Electric) Bikeshare Program* and Measure T-22-B, *Implement Electric Bikeshare Program*, from the Handbook.

### Scale of Application (Locational Context)

Plan/Community (urban, suburban)

## GHG Reduction Formula

$$A = \frac{\boldsymbol{B} \times \boldsymbol{C} \times D \times \left((E \times F) - (G \times H)\right)}{I \times J}$$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Percent reduction in GHG emissions from transitioning an existing bikeshare system to electric bikes | 0–0.059 | % | calculated |
| User Inputs | | | | |
| **B** | Percent of residences in plan/community with access to traditional bikeshare system | 0–100 | % | user input |
| **C** | Percent of bikeshare bikes transitioned to electric bikeshare | 0–100 | % | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| D | Daily bikeshare trips per person | 0.021 | trips per day per person | MTC 2021 |
| E | Vehicle to electric bikeshare substitution rate | 35 | % | Fitch et al. 2021 |
| F | Electric bikeshare average one-way trip length | 2.1 | miles per trip | Fitch et al. 2021 |
| G | Vehicle to conventional bikeshare substitution rate | 19.6 | % | McQueen et al. 2020 |
| H | Conventional bikeshare average one-way trip length | 1.4 | miles per trip | Lazarus et al. 2019 |
| I | Daily vehicle trips per person | 1.7 | trips per day per person | FHWA 2023 |
| J | Regional average one-way vehicle trip length | Table T-10.1 (Handbook) | miles per trip | CAPCOA 2021 |

Further explanation of key variables:

- ($B$) – Access to bike sharing is measured as the percentage of residences in the plan/community within 0.25 mile of a bikeshare station. For dockless bikes, users can assume that all residences within 0.25 mile of the designated dockless service area would have access.
- ($C$) – This is the percentage of bikes within the existing system that are switched from conventional bikeshare bikes to e-bikes. For example, if a system with 100 conventional bikes retires 50 bikes and replaces them with 50 e-bikes, then this would represent a 50 percent transition. This calculation assumes that a bikeshare transition is not combined with a bikeshare expansion. If it is, the new areas can be estimated using T-22A and T-22B from the Handbook.
- ($D$) – An analysis of bike share service areas in the San Francisco Bay Area estimated that in locations with access to bike sharing, there were between 21 and 25 bikeshare trips per day per 1,000 residents (MTC 2021). To be conservative, the low end of this range is cited.

- ($E$) – A study of dockless electric bike share in Sacramento found that the substitution rate of vehicles trips by electric bikeshare trips was 35 percent (Fitch et al. 2021).
- ($F$) – A study of dockless electric bike share in Sacramento found that the average one-way bikeshare trip was 2.1 miles (Fitch et al. 2021).
- ($G$) – A literature review of several academic and government reports found that the average car trip substitution rate by bikeshare trips was 19.6 percent. This included bikeshare programs in Washington D.C., Minneapolis, and Montreal (McQueen et al. 2020).
- ($H$) – A case study on average trip lengths for pedal and electric bikeshare programs in San Francisco reported a one-way pedal bikeshare trip of 1.4 miles (Lazarus et al. 2019).
- ($I$) – A summary report of the 2022 NHTS data found that the average person in the United States takes 1.7 vehicle trips per day (FHWA 2023).
- ($J$) – Ideally, the user will calculate auto trip length for a plan/community at a scale that is appropriate to the geographical area of the electrification efforts. Potential data sources include the MPO travel model, NHTS California Supplement (preferred), or local survey efforts. If the user is not able to provide a plan-specific value using one of these data sources, they have the option to input the existing regional average one-way auto trip length for one of the six most populated core-based statistical areas (CBSA) in California, as presented in Table T-10.1 in Appendix C of the Handbook (FHWA 2017). Trip lengths are likely to be longer for areas not covered by the listed CBSAs, which represent the denser areas of the state.

## GHG Calculation Caps or Maximums

### Measure Maximum

($A_{max}$) – For projects that use default CBSA data from Table T-10.1 in Appendix C of the Handbook, the maximum percent reduction in GHG emissions (A) is 0.059 percent. This maximum scenario is presented in the below example quantification.

### Subsector Maximum

$\left(\sum A_{max_{T-18\ through\ T-22D}} \leq 10\%\right)$ – This measure is in the Neighborhood Design subsector. This subcategory includes Measures T-18 through T-22-C. The VMT reduction from the combined implementation of all measures within this subsector is capped at 10 percent.

## Example GHG Reduction Quantification

The user is transitioning from a large conventional bikeshare system to an electric bikeshare system. For this example, the project is in the Los Angeles-Long Beach-Anaheim CBSA, and the one-way vehicle trip length would be 9.72 miles ($J$). If we assume that 100 percent of the residents in the plan/community have bikeshare access ($B$) and that the fleet is fully transitioning ($C$), the user would reduce GHG emissions from the plan/community VMT by 0.059 percent.

$$A = \frac{\mathbf{100}\% \times \mathbf{100}\% \times 0.021\,\frac{trips}{day\ person} \times \left(35\% \times 2.1\,\frac{mi}{trip} - 19.6\% \times 1.4\,\frac{mi}{trip}\right)}{1.7\,\frac{trips}{day\ person} \times 9.72\,\frac{mi}{trip}} = 0.059\%$$

## Measure Co-Benefits

### Improved Air Quality

The percent reduction in GHG emissions ($A$) would be the same as the percent reduction in NOx, CO, $NO_2$, $SO_2$, and PM. Reductions in ROG emissions can be calculated by multiplying the percent reduction in GHG emissions ($A$) by an adjustment factor of 87 percent. See *Adjusting VMT Reductions to Emission Reductions* in the Handbook for further discussion.

## Energy and Fuel Savings

The percent reduction in vehicle fuel consumption would be the same as the percent reduction in GHG emissions ($A$). This quantification methodology does not account for the increase in electricity used to charge the vehicles or the fuel consumption from vehicle travel of program employees picking up and dropping off bikes.

## VMT Reductions

The percent reduction in VMT would be the same as the percent reduction in GHG emissions ($A$). This quantification methodology does not account for the miles traveled from vehicle travel of program employees picking up and dropping off bikes.

## Sources

California Air Pollution Control Officer's Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2*. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

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Metropolitan Transportation Commission (MTC). 2021. *Technical Methodology to Estimate Greenhouse Gas Emissions for Plan Bay Area 2050*. Available: https://www.planbayarea.org/sites/default/files/documents/Technical-Methodology-Memo-to-CARB_final.pdf. Accessed: December 2023.

## T-46. Provide Transit Shelters

### Description

For this measure, a local government or transit agency provides amenities that make it more comfortable and safer to wait for the bus. The two interventions which have proven to lead to changes in rider perceptions are adding bus shelters and adding real-time arrival information. Research into transit ridership shows that adding these amenities decreases both the real and the perceived wait time for riders, which impacts riders' willingness to ride. This measure requires that bus shelters must have benches because the combined effect inclusive of benches was measured in the studies cited. Lighting is not required as part of these amenities but is, nonetheless, recommended as it increases rider perceptions of safety at night.

### Scale of Application (Locational Context)

Plan/Community (urban, suburban)

### GHG Reduction Formula

$A1 = \boldsymbol{B} \times \frac{\boldsymbol{C}}{\boldsymbol{D}} \times \boldsymbol{E} \times \frac{F}{G} \times (-H + I1) \times J$ (for bus shelters only)

$A2 = \boldsymbol{B} \times \frac{\boldsymbol{C}}{\boldsymbol{D}} \times \boldsymbol{E} \times \frac{F}{G} \times (-H + I2) \times J$ (for bus shelters and real-time arrival information)

### GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A1, A2 | Percent reduction in GHG emissions from vehicle travel in plan/community | 0–0.32 | % | calculated |
| User Inputs | | | | |
| **B** | Number of transit stops with new bus shelters and benches | [ ] | count | user input |
| **C** | Average number of boardings per day at each transit station with added amenities | [ ] | boardings/day | user input |
| **D** | Average number of boardings per day across the transit agency | [ ] | boardings/day | user input |
| **E** | Transit mode share in the city of note | Table T-3.1 (Handbook) | % | CAPCOA 2021 |
| Constants, Assumptions, and Available Defaults | | | | |
| F | Percent of transit users who would otherwise drive | 83.3 | % | FHWA 2018 |
| G | Average auto occupancy | 1.45 | riders/vehicle | FHWA 2023 |

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| H | Percent of total travel time spent waiting (transit trips) | 24.9 | % | FHWA 2023 |
| I1 | Percent of perceived total travel time spent waiting (transit trips with shelters) | 20.3 | % | Fan 2016 |
| I2 | Percent of total travel time spent waiting (transit trips with shelters and RTI) | 15.8 | % | Watkins 2011 |
| J | Wait time elasticity | -0.54 | unitless | Taylor et al. 2009 |

Further explanation of key variables:

- ($B$) – This input is the number of bus stops that get equipped with new amenities (either shelters or shelters and real-time information).
- ($C$) – This input is the average number of boardings per day at the bus stop before the new amenities are added.
- ($D$) – This input is the average number of boardings per day across the entire transit agency.
- ($E$) – This is the transit mode share in the city where the bus amenities are being added. It is recommended that users use local data from the California extension of the NHTS or the U.S. Census for where the project(s) is located. The user can also use the values for CBSAs in the case where the projects are spread out across multiple cities.
- ($F$) – This constant is based on the percentage of trips taken by car from NHTS weighted by transit ridership and number of cars available in the household to account for the fact that some riders do not have a choice to take transit and would ride regardless of the wait time. This value from FHWA 2018 represents pre-COVID-19 pandemic conditions but is the most recent value from FHWA.
- ($G$) – This is the average car occupancy for trips taken as of the latest version of the NHTS in 2022. This value accounts for the effects of the COVID-19 pandemic.
- ($H$) – This value represents the percentage of the total transit trip travel time that is composed of waiting and is derived from average wait times and travel times in the NHTS in the Pacific region.
- ($I1$, $I2$) – This represents the percentage of the total transit trip travel time that is composed of waiting after the addition of transit amenities. This is derived from the average wait times and travel times in the NHTS and the perceived wait time changes found in the Fan 2016 paper and the Watkins 2011 paper.
- ($J$) – This elasticity is sourced from a study (Taylor et al. 2009) that uses data from LA Metro to estimate the effect of wait time and travel time on ridership across the system.

## GHG Calculation Caps or Maximums

### Measure Maximum

($A_{max}$) – The percent reduction in GHG emissions ($A$) is capped at 0.32 percent. This assumes that the CBSA is San Francisco-Oakland-Hayward, which has a default transit mode share for all trips of 11.38 percent.

### Subsector Maximum

( $\sum A_{max\ T\text{-}25\ through\ T\text{-}29} \leq 15\%$) – This measure is in the Transit subsector. This subcategory includes Measures T-25 through T-29 in the Handbook. The VMT reduction from the combined implementation of all measures within this subsector is capped at 16 percent.

## Example GHG Reduction Quantification

The user reduces VMT by constructing twelve transit shelters in Oakland with real time information for a bus system that has an average of 15,000 boardings per day ($D$) and 300 boardings per day at each of the stops ($C$) before the project. This leads to a reduction in transportation related GHG emissions of 0.077 percent.

$$\mathrm{A} = \mathbf{12} \times \frac{\mathbf{300}}{\mathbf{15,000}} \times \mathbf{11.38}\% \times \frac{83.3\%}{1.45} \times (-\ 24.9\% + 15.8\%) \times -0.54 = \ 0.077\%$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, VMT reductions, enhanced pedestrian or traffic safety, improved public health, and social equity. This section defines the methods for quantifying improved air quality, energy and fuel savings, and VMT reductions.

### Improved Air Quality

The criteria pollutants CO, $NO_2$, $SO_2$, and PM are considered local pollutants that can be deposited and potentially affect populations near the emissions source. Accordingly, projects that reduce localized criteria pollutant emissions can improve ambient air quality. The percent reduction in GHG emissions (A*)* achieved by the measure would be the same as the percent reduction in localized criteria pollutant emissions. This measure would also reduce emissions of ozone precursors (NOx and ROG), which are regional pollutants. While the percent reduction in NOx emissions would be the same as the percent reduction in GHG emissions, the percent reduction in ROG would not. The percent reduction in GHG emissions must be multiplied by an adjustment factor of 87 percent to account for the evaporative ROG emissions that would not be reduced by this measure. See *Adjusting VMT Reductions to Emission Reductions* in the Handbook for further discussion.

### Energy and Fuel Savings

The percent reduction in vehicle fuel consumption achieved by the measure would be the same as the percent reduction in GHG emissions ($A$).

#### VMT Reductions

The percent reduction in VMT achieved by the measure would be the same as the percent reduction in GHG emissions (*A*).

### Sources

California Air Pollution Control Officer's Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2*. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed December 2023.

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# Energy

Energy is a key sector in the Handbook, and the addition of two measures will provide users with more options to reduce emissions from this sector. The Handbook includes a comprehensive list of measures for improving energy efficiency, increasing renewable energy, and decarbonizing buildings. The energy measures presented in this memorandum fit within the existing framework of strategies from the Handbook. One measure (Cool Pavements) was included as a non-quantified measure in the Handbook. ICF has re-assessed the measure to define quantitative methods. The other measure (Biomass Energy) involves transitioning to combustion of biofuels for building energy use. The Biomass Energy measure is an exception among the other measures presented in this memorandum because lifecycle emissions are presented. No quantification methods can be defined without a lifecycle analysis for this measure.

## E-21. Install Cool Pavement

### Description

This measure involves installing cool pavements in place of dark pavements. Cool pavements help to lower ambient outdoor air temperatures when compared to dark-colored, heat-absorbent pavements such as asphalt. This reduces the electricity needed to provide cooling, thereby reducing associated GHG emissions depending on the project parameters (e.g., climate, carbon intensity of local utility). Implementation of this measure may result in limited or no GHG reductions for highly developed areas with tall buildings or in urban canyons[6], such as in a downtown or commercial area, or areas with extensive tree canopy cover. Tall buildings and tree canopies restrict the amount of sunlight reaching the street surface, and thus limited additional cooling would be achieved by the pavement surface. Furthermore, installing cool pavements in areas with tall buildings or in urban canyons may result in an increased heating demand during the cooler months. Cool pavement installation should be prioritized in paved areas in open spaces with high urban heat island effects, such as major freeways, highways, arterial roads, and parking lots (Altostratus Inc. 2020).

## Scale of Application

Project/Site and Plan/Community within Electricity Demand Forecast Zones (EDFZ) 4, 5, 7, 11, 12, 16, 17 and 18.

## GHG Reduction Formula

$$A_C = \left(\frac{\boldsymbol{B}_c \times D}{E}\right) \times \mathrm{J}$$

$$K_H = \left(\frac{\boldsymbol{B}_H \times I}{E}\right) \times \mathrm{M}$$

$$L = \left(\frac{((A_c \times \mathrm{F}) + (K_H \times \mathrm{G}))}{N}\right)$$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Reduction in electricity demand from the installation of cool pavements | [ ] | MWh/year | calculated |
| K | Increase in natural gas demand from the installation of cool pavements | [ ] | MMBtu/year | calculated |
| L | GHG emission reductions from the installation of cool pavements | [ ] | MT $CO_2e$/ year | calculated |
| User Inputs | | | | |
| **B** | Amount of cool pavement that is being constructed | [ ] | $ft^2$ | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| C | EDFZ for electricity demand: 4, 5, 7, 11, 12 ,16, 17 or 18. | See Figure E-1.1 and Table E-1.1 | integer | CAPCOA 2021 |

[6] The *urban canyon effect*, or urban canyon, occurs when tall, densely grouped buildings flank both sides of a street, creating an artificial canyon effect. An urban canyon may limit the amount of sunlight reaching the street surface during daytime hours.

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| | | (Handbook) | | |
| H | EDFZ for natural gas demand: 5 or 16 | See Figure E-1.1 and Table E-1.1 (Handbook) | integer | CAPCOA 2021 |
| D | Cool pavement maximum energy saving per year | See Table E-21.1 in Appendix A | kWh/year/m$^2$ | Lawrence Berkely National Laboratory 2017a, 2017b |
| E | Converting square feet to square meters | 10.76 | ft$^2$/m$^2$ | conversion |
| F | Greenhouse gas intensity factor by California Electricity Provider | See Table E-4.3 and Table E-4.4 (Handbook) | lbs $CO_2e$/MWh | CAPCOA 2021 |
| G | Natural Gas Emission Factors | See Table E-4.5 (Handbook) | lbs $CO_2e$/MMBTU | CAPCOA 2021 |
| I | Cool pavement maximum heating savings per year | EDFZ 5 = -0.00829<br>EDFZ 16 = -0.0054 | therms/year/m$^2$ | Lawrence Berkeley National Laboratory 2017b |
| J | Converting kilowatt hours to megawatt hours | 0.001 | MWh/kWh | conversion |
| M | Converting therms to MMBTU | 0.1 | MMBTU/therms | conversion |
| N | Converting pounds to metric tons | 2,204.62 | lbs/MT | conversion |

Further explanation of key variables:

- (*B*) – The amount of cool pavement that is being constructed.
- (*C, H*) – Climate zones are specific geographic areas of similar climatic characteristics, including temperature, weather, and other factors that affect building energy use. The California Energy Commission (CEC) has specified numerous EDFZs in California, which are referenced in CEC's California Commercial End-Use Survey and Residential Appliance Saturation Study. This measure would only be applicable to certain EDFZs where research was done on calculating energy savings from the installation of cool pavement.
- (*D)* – The maximum electricity savings (kWh) per year per meter of installed cool pavement. This would only be applicable to eight EDFZs where electricity savings were quantified. The electricity savings and the EDFZs zone are provided in Table E-21.1 in Appendix A.
- (*F, G*) – GHG intensity factors for major California utilities within the supported EDFZs are provided in Tables E-4.3 through Tables E-4.5 in Appendix B of the Handbook. If the project study area is not serviced by a listed utility, or the user is able to provide a project-specific value (i.e., for the future year not referenced in Appendix B), the user should use that specific value in the GHG calculation formula. If the utility is not known, users may elect to use the statewide grid average carbon intensity.
- (*I*) – The maximum additional heating requirements (therms) per year per meter of installed cool pavement. This would only be applicable to EDFZ 5 and EDFZ 16, because these areas were the only two included in the research paper that describes the additional heating requirement

from cool pavements. For other areas, users could conservatively use the higher value from EDFZ 16 to estimate the additional heating requirement.

## GHG Calculation Caps or Maximums

The maximum GHG emission reductions from this measure are tied to the total amount of area that cool pavement can be installed within a jurisdiction within a supported EDFZ and the GHG intensity factors from the local utilities supporting that jurisdiction.

## Example GHG Reduction Quantification

A City within EDFZ 16 is working on a pilot program that will install cool pavement on a 5 mile, 4-lane stretch of an arterial roadway. The total area of this roadway that would be covered is 1,267,200 square feet ($B_C$, $B_H$). Following the formulas above, this pilot program would result in a reduction of 3.28 MTCO2e/yr from energy savings.

The following default values from tables in Appendix A (of this memorandum) and the Handbook are used.

- (D) – The cooling savings of 0.182 kWh/m$^2$/yr (Table E-21.1 in Appendix A) for EDFZ 16.
- (I) – The heating savings of -0.00554 therms/m$^2$/yr for EDFZ 16.
- (F) – The Los Angeles Department of Water & Power carbon intensity of electricity of 694 lbs $CO_2$e per MWh ($EF_{EGHG}$) (Table E-4.3 from the Handbook).
- (G) – The natural gas emission factor of 117.32 lbs $CO_2$e per MMBTU for residential uses (Table E-4.5 from the Handbook).

$$A_C = \left(\frac{\mathbf{1,267,200}\ \boldsymbol{ft^2}\ \times 0.182\ kWh/m^2/yr}{10.76\ ft^2/m^2}\right) \times 0.001\text{MWh/kWh}$$

$$A_C = 21.43\ \text{MWh/yr}$$

$$K_H = \left(\frac{\mathbf{1,267,200}\ \boldsymbol{ft^2}\ \times -0.00554\ therms/m^2/yr}{10.76\ ft^2/m^2}\right) \times 0.1\ MMBTU/therms$$

$$K_H = -65.24\ \text{MMBtu/yr}$$

$$L = \left(\frac{((21.43\ \text{MWh/yr} \times 694\ \text{lbs}\ CO_2\text{e/MWh}) + (-65.24\ \text{MMBTU/yr} \times 117.32\ \text{lbs}\ CO_2\text{e/MMBTU})}{2{,}204.62\ lbs/MT}\right)$$

$$L = 3.28\ \text{MTCO}_2\text{e/yr}$$

## Measure Co-Benefits

Successful implementation of this measure would achieve electricity ($A_C$) savings. However, while the measure will achieve electricity savings it can increase natural gas consumption ($K_H$) and potentially worsen ambient air quality ($U$).

#### Electricity Reduction Formula

$$A_C = \left(\frac{\boldsymbol{B}_c \times D}{E}\right) \times \mathrm{J}$$

#### Natural Gas Increase Formula

$$K_H = \left(\frac{\boldsymbol{B}_H \times I}{E}\right) \times \mathrm{M}$$

#### Criteria Pollutant Increase Formula

$$U = \left(\frac{(|\boldsymbol{K_H}| \times \mathrm{G})}{X}\right)$$

#### Criteria Pollutant Emissions Increase Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| U | Increase in criteria pollutant emissions from building energy | [ ] | tons per year | calculated |
| User Inputs | | | | |
| **K** | Increase in natural gas demand from the installation of cool pavements | [ ] | MMBTU/year | calculated |
| Constants, Assumptions, and Available Defaults | | | | |
| H | EDFZ for natural gas demand: 5 or 16 | See Figure E-1.1 and Table E-1.1 (Handbook) | integer | CAPCOA 2021 |
| G | Criteria pollutant emission factors of natural gas | See Table E-4.5 (Handbook) | lbs/MMBTU | CAPCOA 2021 |
| X | Converting pounds to short tons | 2,000 | lbs/tons | conversion |

Further explanation of key variables:

- ($K_H$) – Since $K_H$ is a negative value in the above equation, the absolute value is used to calculate the positive increase in criteria pollutant emissions.
- ($G$) – Natural gas GHG emission factors for residential and non-residential uses are found in Table E-4.5 of the Handbook. When choosing between residential or non-residential, it is recommended that users use the emission factor representing the most prominent land use near the cool pavement that is being constructed.

## Sources

Altostratus Inc. 2020. *Capital Region Heat Pollution Reduction: Atmospheric Modeling for the Development of a Regional Heat Pollution Reduction Plan*. February 26. Available: https://www.airquality.org/LandUseTransportation/Documents/Altostratus_Final_Report.pdf. Accessed: January 2023.

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## E-26. Biomass Energy

### Description

This measure involves installing new biomass or biofuel electricity generation (or cogeneration). Although the direct combustion emissions for biofuels are generally on-par with other forms of fossil fuel energy, biofuels have a lower life-cycle carbon intensity due to the uptake of carbon from plants used to produce that fuel. A reasonable reference point for this carbon intensity would be the average carbon intensity of the electricity in the utility that would receive power from this new biomass plant.

### Scale of Application

All - Project/Site and Plan/Community

### GHG Reduction Formula

$A = \boldsymbol{B} \times C \times D \times [-E + F] \times G$

### GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | Annual emissions reduction from biomass plant generation | [ ] | MT $CO_2e$ | calculated |
| User Inputs | | | | |
| **B** | Rated peak generation power | [ ] | MW | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| C | Intended hours of operation per year | 8,760 | hours | conversion |
| D | Capacity factor of generation type | See Table E-26.1 (Appendix A) | % | U.S. EIA 2023 |
| E | Lifecycle carbon intensity of biomass sources | See Table E-26.2 (Appendix A) | lbs $CO_2e$/MWh | EPRI 2013 |
| F | Lifecycle carbon intensity of CA electricity | 642.9 | lbs $CO_2e$/MWh | CARB 2022 |
| G | Conversion from lbs to MT | 0.000454 | MT/lbs | conversion |

Further explanation of variables:

- $(B)$ – This is the rated peak power output of the generators used by the power plant. This is often referred to as the nameplate value.
- $(C)$ – This is the number of hours per year which the utility intends to operate for, not including normal operational breaks such as maintenance.
- $(D)$ – The capacity factor corrects for the fact that power plants do not always operate at their rated peak power due to a variety of operational and economic factors in order to estimate the actual amount of electricity generation at a utility-scale power plant.
- $(E)$ – The lifecycle carbon intensity of each biomass power source may be available using data from the Low Carbon Fuel Standard program. For generic projects with known fuels, this can be found using the data provided from the Electric Power Research Institute report provided.
- $(F)$ – This value represents the carbon intensity of electricity displaced by the biomass power plant.

## GHG Calculation Caps or Maximums

None.

## Example GHG Reduction Quantification

In this example, a user installs a new 1-MW $(B)$ biomass plant which burns dedicated woody crops that they intend to operate year-round. In 2023, the lifecycle carbon intensity of power for California is estimated to be 642.9 lbs $CO_2$e/ MWh $(F)$. The new plant, because it will burn wood, is estimated to have a capacity factor of 59 percent $(D)$ (see Table E-26.1 in Appendix A) and a mean carbon intensity of 189.6 lbs $CO_2$e/MWh $(E)$ (see Table E-26.2 in Appendix A).

$$\mathrm{A} = \mathbf{1\ MW} \times 8{,}760\ \mathrm{hrs} \times 59\% \times \left[-189.6\ \frac{lbs\ CO_2e}{MWh} + 642.9\ \frac{lbs\ CO_2e}{MWh}\right] \times 0.000454\,\frac{\mathrm{MT}}{\mathrm{lbs}} = 1{,}063.6\,\frac{\mathrm{MT}\ CO_2e}{\mathrm{year}}$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved energy and fuel savings, and enhanced energy security. This section defines the methods for quantifying energy and fuel savings.

### Energy and Fuel Savings

Fossil fuel energy savings will be achieved through the use of biomass energy. Since natural gas represents the majority of base load electricity in California, it is assumed that each kWh of biomass electricity displaces a kWh of gas-fired electricity. Nonetheless, these types of generators require a constant source of feedstock that could lead to unintended consequences of land use change depending on the fuel type.

### Energy Reduction Formula

$$H = \frac{\boldsymbol{B} \times C \times D \times I}{J}$$

#### Electricity Reduction Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| H | Natural gas saved | [ ] | therms | calculated |
| Constants, Assumptions, and Available Defaults | | | | |
| I | Heat rate | 7,728,000 | BTU/MWh | CEC 2020 |
| J | Conversion from BTU to therms | 100,000 | BTU/therms | conversion |

Further explanation of key variables:

- (*I*) – This value represents the average amount of energy needed to produce a MWh of electricity across all natural gas power plants in the state of California as of 2019.

#### Energy Security

Energy security is one of the main benefits of using biomass fuels, because they can easily be grown in the United States and can also take advantage of waste fuel streams like fuel from agricultural waste. This can help to offset the importation of fossil fuels like natural gas from Canada.

### Sources

California Air Resources Board (CARB). 2022. *2023 Carbon Intensity Values for California Average Grid Electricity Used as a Transportation Fuel in California and Electricity Supplied Under the Smart Charging or Smart Electrolysis Provision*. Available: https://ww2.arb.ca.gov/sites/default/files/classic/fuels/lcfs/fuelpathways/comments/tier2/2023_elec_update.pdf. Accessed: December 2023.

California Energy Commission. 2020. *Thermal Efficiency of Natural Gas-Fired Generation in California: 2019 Update.* Available: https://efiling.energy.ca.gov/getdocument.aspx?tn=233380 Accessed: December 2020.

Electric Power Research Institute (EPRI). 2013. *Literature Review and Sensitivity Analysis of Biopower Life-Cycle Assessments and Greenhouse Gas Emission*. Available: https://www.epri.com/research/products/000000000001026852. Accessed: August 2023.

U.S. Energy Information Administration (U.S. EIA). 2023. *Table 6.07.B Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels*. Electric Power Monthly. Available: https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_07_b-. Accessed: August 2023.

## Solid Waste

One additional measure is being proposed within the Solid Waste sector, which aims to recover edible food that is wasted. The Handbook includes two quantified measures in the Solid Waste sector, and the goal of both of those measures is to divert waste away from the landfill where it will undergo decomposition and generate methane emissions. Diverting waste to another pathway (i.e., recycling or composting) avoids the decomposition emissions that occur in a landfill. The food recovery measure is similar in that the goal is also to divert waste from the landfill, but it aims to do so in a specific way that offers several co-benefits.

Like the biomass energy measure, the food recovery measure involves lifecycle emissions. Similar to the waste-related measures in the Handbook, the methods for quantifying this measure account for upstream and downstream emissions associated with the waste management pathways with and without the measure. As such, the same cautionary note in the Handbook applies here, and users should use discretion when comparing reductions from this measure to operational emissions inventories, which may not include lifecycle emissions.

## S-3. Require Edible Food Recovery Program Partnerships with Food Generators

### Description

This measure requires that food service establishments, wholesale providers, and retail sources of edible food waste partner with food recovery programs. Food recovery programs collect edible foods, which would otherwise be landfilled or composted, from commercial production and distribution channels and redistribute the food for consumption by those in need. This measure avoids emissions from the decomposition of non-diverted organic material in landfills. As noted above, this measure's reductions are lifecycle emissions, because it results in reductions in upstream and downstream emissions, such as production and transportation related emissions.

### Scale of Application

All - Project/Site and Plan/Community

### GHG Reduction Formula

$$A = \sum_{\boldsymbol{E}} \left[ \left( \frac{G \times \boldsymbol{H}}{L} \right) + \left( \frac{\boldsymbol{I} \times \boldsymbol{J} \times K}{M} \right) \right]$$

$$B = \sum_{\boldsymbol{F}} \left[ \left( (\boldsymbol{N} \times O + P) \times \left( \frac{Q}{R \times M} \right) \right) + \left( \frac{S \times \boldsymbol{T} \times U}{M} \right) \right]$$

$$C = \left( \frac{\boldsymbol{V}}{W} \right) \times X$$

$$D = C - (A + B)$$

### GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A | GHG emissions from transportation vehicles | [ ] | MT $CO_2e$/year | calculated |
| B | GHG emission from refrigeration equipment | [ ] | MT $CO_2e$/year | calculated |
| C | GHG emission reductions from recovery of edible food | [ ] | MT $CO_2e$/year | calculated |
| D | Net GHG emissions from the recovery of edible foods | [ ] | MT $CO_2e$/year | calculated |

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| User Inputs | | | | |
| **E** | Number and type of identical delivery vehicle(s) | [ ] | unitless | user input and see Table S-3.1 (Appendix A) |
| **F** | Number and type and number of identical refrigeration unit(s) | [ ] | unitless | user input and see Table S-3.1 (Appendix A) |
| **H** | Average miles per year for the delivery vehicle(s) | [ ] | miles/year | user input |
| **I** | Leakage rate of the Transportation Refrigeration Unit (TRU), if applicable | [ ] | % | user input |
| **J** | The TRU refrigerant charge size, if applicable | [ ] | lbs/year | user input |
| **N** | Volume of refrigeration compartment | [ ] | $ft^3$ | user input |
| **T** | Refrigerant charge size, if known. | [ ] or Table S-3.1 (Appendix A) | lbs | user input or CARB 2020a |
| **V** | Amount of edible food recovered per year | [ ] | lbs | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| G | Delivery vehicle GHG emission factor | See Table T-30.2 (Handbook) | g $CO_2e$ /miles | CAPCOA 2021 |
| L | Grams to metric ton conversion factor | 1,000,000 | g/MT | conversion |
| K | Refrigerant GWP, default of R-134A is assumed for TRU | See Table R-1.1 (Handbook); default value is 1,430 | unitless | CAPCOA 2021 |
| M | Pounds to metric ton conversion factor | 2,204.62 | lbs/MT | conversion |
| O | Electricity consumption of refrigeration unit per year per cubic feet | See Table S-3.1 (Appendix A) | $kWh/year/ft^3$ | CARB 2020b and 10 CFR 431.66 |
| P | Constant electricity consumption of a refrigeration unit per year | See Table S-3.1 (Appendix A) | kWh/Year | CARB 2020b and 10 CFR 431.66 |
| Q | GHG intensity factor by California Electricity Provider | See Table E-4.3 and Table E-4.4 (Handbook) | lbs CO2e/MWh | CAPCOA 2021 |
| R | Converting MWh to kWh | 1,000 | kWh/MWh | conversion |
| S | Annual Average Leakage rate per year of the refrigeration unit | See Table S-3.1 (Appendix A) | % | CARB 2020b |

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| U | Refrigeration unit refrigerant GWP | See Table R-1.1 (Handbook) | unitless | CAPCOA 2021 |
| W | Pounds to short ton conversion factor | 2,000 | lbs/ton | Conversion |
| X | Edible food waste recovery emission reduction factor (Landfill or Composting) | 1.78 (Landfill) 1.49 (Composting) | MT $CO_2e$/ton | CARB 2020c and Venkat 2012 |

Further explanation of key variables:

- ($E$) – The type of delivery vehicles that are supported for this measure are provided in Table S-3.1 in Appendix A. The user will need to specify how many of the individual delivery vehicle types are being used and run different calculations for each different type of delivery vehicle. The equation cannot be run without specifying (1) the delivery vehicle from Table S-3.1, and (2) the number of delivery vehicles.
- ($F$) – The type of refrigeration units that are supported for this measure are provided in Table S-3.1 in Appendix A. The user will need to specify how many of the individual refrigeration unit types are being used and run different calculations for each different type of refrigeration unit. The equation cannot be run without specifying the (1) type of refrigeration unit from Table S-3.1 and (2) the number of refrigeration units.
- ($G$) – This value is used to calculate the emissions generated by delivery vehicles transporting the recovered food. Delivery vehicle GHG emission factors (grams $CO_2e$ per mile) are provided in Table T-30.2 of the Handbook.
- ($H$) – This input represents the number of miles traveled by the delivery vehicle(s) used to transport the recovered food.
- ($I$) – This value represents the rate at which refrigerants leak from the transportation refrigeration unit in the delivery vehicle.
- ($J$) – This value represents the quantity of refrigerants used in the delivery vehicles.
- ($K$) – This value is the GWP for the refrigerants used in the delivery vehicles. GWP values are provided in Table R-1.1 of the Handbook.
- ($N$) – This value represents the volume of the refrigeration compartment used to store the recovered food.
- ($O$) – This value is used to calculate the emissions generated by refrigeration units where the recovered food is stored. The electricity consumption of the refrigeration unit per year per cubic feet are provided in Table S-3.1 in Appendix A.
- ($P$) – This value is used to calculate the quantity of energy consumed in the refrigeration units. The constant electricity consumption of a refrigeration unit per year are provided in Table S-3.1 in Appendix A.
- ($Q$) – Electricity GHG emission factors for the different utilities within the State of California are provided in Tables E-4.3 and Table E-4.4 in the Handbook.

- ($S$) – This value represents the rate at which refrigerants leak from the refrigeration unit.
- ($T$) – This value represents the quantity of refrigerants used to store the recovered food.
- ($U$) – This value is the GWP for the refrigerants used in the refrigeration storage units. GWP values are provided in Table R-1.1 of the Handbook.
- ($X$) – This value represents the lifecycle GHG emissions that are reduced from one short ton of recovered food from a landfill or from a composting facility.

## GHG Calculation Caps or Maximums

None. However, it is possible that the GHG emissions from transportation and refrigeration use exceed the emission reduction from the edible food recovery, resulting in a disbenefit for this measure.

## Example GHG Reduction Quantification

A food bank located in the City of Los Angeles with a 960 cubic feet commercial walk-in refrigerator with solid doors ($F$, $N$) is recovering edible food waste from local restaurants. Based on the collection in 2023, the food bank is estimating that it will be able to recover and donate approximately 25,000 pounds of edible food in 2025 from the local restaurants ($V$). The food bank will be using a gasoline refrigerated van ($E$) to recover the edible food. The food bank is anticipating that the total distance traveled per day is approximately 20 miles, or approximately 7,300 miles per year ($H$). Following the equations above, the recovery of the 25,000 pounds of edible food would result in a reduction of 5.98 $MTCO_2e$/year.

Default values taken from the tables in Appendix A (of this memorandum) and the Handbook include the following.

- Carbon intensity of 556.3 grams $CO_2e$/mile for the gasoline refrigerated van ($G$).
- The average yearly leakage rate of 24 percent ($R_{Leak}$), which is modeled as a percentage in the formula (i.e., 0.24).
- The average yearly refrigerant charge size of 4 lbs ($J$).
- The global warming potential (GWP) of 1,430 for R-134A ($K$).
- The electricity consumption per year per cubic foot of 36.5 kWh/year/$ft^3$ for the commercial refrigerator with solid doors ($O$).
- The yearly constant electricity consumption of 744.6 kWh/year ($P$).
- The Los Angeles Department of Water & Power carbon intensity of electricity of 694 lbs $CO_2e$/MWh ($Q$).
- The leakage rate of 15 percent for commercial refrigerators ($S$).
- The average yearly refrigerant charge size of 31.4 pounds ($T$).
- The GWP of 150 for refrigeration unit refrigerants ($U$) was assumed.
- The edible food waste recovery emission reduction factor of 1.78 MTCO2e/ton ($X$).

$$A = \sum_{1} \left[ \left( \frac{556.3\ g\ CO_2e/mi\ \times \mathbf{7,300\ mi/year}}{1{,}000{,}000\ g/MT} \right) + \left( \frac{\mathbf{0.24}\ \times \mathbf{4\ lbs/yr} \times 1{,}430}{2{,}204.62\ lbs/MT} \right) \right]$$

$$A = 4.68\ MTCO2_e/yr$$

$$B = \sum_{1} \left[ \left( \left( \left( \mathbf{960 ft^3} \times 36.5\ kWh/year/ft^3 \right) + 744.6\ kWh/year \right) \times \left( \frac{694\ lbs\ CO2e/MWh}{2{,}204.62 \frac{lbs}{MT} \times 1{,}000\ kWh/MWh} \right) \right) + \left( \frac{0.15 \times \mathbf{31.4\ lbs/year} \times 150}{2{,}204.62\ lbs/MT} \right) \right]$$

$$B = 11.59\ MTCO2_e/year$$

$$C = \left( \frac{\mathbf{25,000\ lbs}}{2{,}000\ lbs/ton} \right) \times 1.78$$

$$C = 22.25\ MTCO2_e/year$$

$$D = 22.25\ MTCO2_e/year - (4.68\ MTCO2_e/year + 11.59\ MTCO2_e/year)$$

$$D = 5.98\ MTCO2_e/year$$

## Measure Co-Benefits

Successful implementation of this measure could achieve water conservation, improved ecosystem health, enhanced food security, social equity, and improved air quality.

### Air Quality Emissions Reduction Formula

$$A2 = \sum_{\boldsymbol{E}} \left[ \left( \frac{G \times \boldsymbol{H}}{\boldsymbol{I}} \right) \right]$$

$$B2 = \sum_{\boldsymbol{F}} \left( (\boldsymbol{J} \times K + L) \times M \right)$$

$$C2 = \left( \left( \frac{N}{O} \right) \times P \right) + \left( \left( \frac{N}{O} \right) \times Q \right)$$

$$D2 = C2 - (A2 + B2)$$

### Air Quality Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A2 | Air quality emissions from transportation vehicles | [ ] | lbs/year | calculated |
| B2 | Air quality emission from refrigeration equipment | [ ] | lbs/year | calculated |
| C2 | Air quality emission reductions from recovery of edible food | [ ] | lbs/year | calculated |

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| D2 | Air quality emissions from the recovery of edible foods | [ ] | lbs/year | calculated |
| User Inputs | | | | |
| **E** | Number and type of identical delivery vehicle(s) | [ ] | unitless | user input and see Table S-3.1 (Appendix A) |
| **F** | Number and type of identical refrigeration unit(s) | [ ] | unitless | user input and see Table S-3.1 (Appendix A) |
| **H** | Average miles per year for the delivery vehicle(s) | [ ] | miles/year | user input |
| **J** | Volume of refrigeration compartment | [ ] | $ft^3$ | user input |
| **N** | Amount of edible food rescued | [ ] | lbs | user input |
| Constants, Assumptions, and Available Defaults | | | | |
| G | ROG, NOX, PM2.5, and diesel PM10 exhaust emission factors | Use EMFAC2021 to calculate | g/miles | EMFAC2021 (CARB 2023) |
| I | Grams to pounds conversion factor | 453.6 | g/lbs | conversion |
| F2 | Type of refrigeration units | See Table S-3.1 (Appendix A) | unitless | CARB 2020b |
| K | Electricity consumption of refrigeration unit per year per feet | See Table S-3.1 (Appendix A) | kWh/year/ $ft^3$ | CARB 2020b |
| L | Constant electricity consumption of a refrigeration unit per year | See Table S-3.1 (Appendix A) | kWh/Year | CARB 2020b |
| M | Electricity air quality emission factor | See Table S-3.2 (Appendix A) | lbs/kWh | CAPCOA 2021 |
| O | Pounds to short ton conversion factor | 2,000 | lbs/ton | conversion |
| P | Avoided transportation for food waste emissions reduction factor | See Table S-3.2 (Appendix A) | lbs/ton | CARB 2020b |
| Q | Avoided landfill flare emission reduction factor | See Table S-3.2 (Appendix A) | lbs/ton | CARB 2020b |

## Sources

California Air Pollution Control Officers Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2.* December. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

California Air Resources Board (CARB). 2020a. *Quantification Methodology: California Department of Resources Recycling and Recovery Food Waste Prevention and Rescue Program*. Available: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_finalfoodwaste_qm_19-20.pdf. Accessed: December 2023.

California Air Resources Board (CARB). 2020b. *Benefits Calculator Tool for the Food Waste Prevention and Rescue Program*. Available: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_finalfoodcalc_19-20.xlsx. Accessed: December 2023.

California Air Resources Board (CARB). 2020c. *Benefits Calculator Tool for the Organics Grant Program*. June. Available: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_organics_finalcalc_6-15-20.xlsx. Accessed: January 2024.

California Air Resources Board (CARB). 2023. *EMission FACtor Model*. Available: https://arb.ca.gov/emfac/. Accessed: December 2023.

Venkat, K. 2012. *The Climate Change and Economic Impacts of Food Waste in the United States*. April. Available: https://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf. Accessed: January 2024.

# Natural and Working Lands

The Handbook currently includes four quantified measures in the Natural and Working Lands sector that involve tree planting, creating new open space, improving management of existing natural lands, and using best practices for managing manure from livestock. This memorandum presents a new measure in this sector, which, in addition to a reduction in GHG emissions, would also result in numerous other benefits. The new measure aims to reduce emissions associated with wildfires by encouraging best practices in managing forests. As noted in the Handbook, methods to quantify GHG reductions from natural and working lands measures are inherently complex given the dynamic variables that influence GHG emissions. Consequently, quantification of measures in this sector often requires the use of external tools and cannot be easily completed by users manually.

## N-7. Wildfire Resilience and Management[7]

### Description

This measure involves implementing fuel treatments in forested areas to minimize the likelihood of severe or catastrophic wildfire behavior, thereby minimizing pyrogenic carbon emissions during a wildfire event. The vast majority of carbon emissions from wildfire events originate from live tree biomass that primarily exists in the overstory canopy. Implementing fuel treatments has the short-term effect of releasing more carbon emissions as understory, ladder fuels, and forest fuel loads are burned. However, across the long term, treated stands will produce fewer emissions as compared to untreated stands because treated stands will produce low to moderate fire severity that does not disturb the carbon stock in the overstory canopy, while untreated stands are far more likely to experience severe behavior that ignites the canopy and releases the stored carbon in the overstory.

ICF initially determined that this measure would be likely quantifiable. After further in-depth review, ICF has determined that, while the measure is quantifiable, the methods to quantify the measure are complex and require a substantial amount of computation that cannot reasonably be completed manually. To determine GHG reductions achieved by this measure, the user needs to calculate the difference in carbon sequestered in a forest under a baseline scenario and the carbon sequestered in a treated forest stand where fuel treatments have been implemented. In the short-

[7] This measure is currently unquantified for the reasons discussed in this section and pending further discussion with SMAQMD.

term, the calculations, in several instances, show that there is no carbon reduction from implementing this measure because the fuel treatments may only reduce wildfire intensity in the long-term, such as over a 30-year period. Thus, to capture the full extent of the carbon reductions from this measure, the user would need to calculate the difference in carbon sequestration for each year and then sum the annual values over the 30-year period. The annual calculations involve separate formulas and variables such as burn rates, carbon consumption values, burn probabilities, above- and below-ground carbon pool values, etc. Each annual calculation for carbon sequestration is comprised of six separate variables, which are themselves comprised of multiple variables, and so forth. Because the calculation for each year requires many individual calculations, the overall 30-year calculation thus requires hundreds of calculations. For this reason, it is not feasible to include this measure in the Handbook because it is dissimilar from the other measures in that it cannot reasonably be computed manually or with a currently available external tool.

Because the limiting factor for this measure is the amount of computation required, ICF notes that the measure could have utility for users if it is incorporated into CalEEMod. Because CalEEMod is an existing modeling platform, the computations required for quantifying this measure could be handled by CalEEMod after the key inputs are entered by the user. As such, ICF recommends that this measure be included in the Handbook, but no quantification methods be presented. Instead, the Handbook could include qualitative information for this measure and instructions for users to quantify the measure in CalEEMod. Additionally, including the measure in CalEEMod would likely yield more accurate results because more precise locational data could be used instead of generalized data.

Given ICF's findings, no quantification methods are presented in this memorandum. ICF recommends incorporating this measure in CalEEMod and not presenting quantitative methods in the Handbook. In CalEEMod, users could rely on the modeling platform to perform the many calculations needed to determine GHG reductions from implementing the measure.

### Scale of Application

All - Project/Site and Plan/Community

### Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, improved public health, and improved ecosystem health.

## N-8. Agricultural Equipment Efficiency

### Description

This measure requires the use of electric- or hybrid-powered, off-road agricultural equipment over conventional diesel-fueled counterparts during agricultural activities. Replacing diesel-powered, off-road agricultural equipment with electric or hybrid-electric equipment reduces fossil fuel combustion and thus GHG emissions. However, all-electric equipment results in GHG emissions from the electricity used to charge the equipment. The indirect GHG emissions increase from electricity must be calculated in addition to the GHG emissions reduction from displaced fossil fuel combustion to estimate the total net GHG emissions reduction achieved by this measure if using electric equipment.

## Scale of Application

All - Project/Site and Plan/Community

## GHG Reduction Formula

$A1 = (\boldsymbol{C} \times D \times F \times G1 \times H) - (\boldsymbol{C} \times D \times \boldsymbol{G2_B} \times I)$

$A2 = (\boldsymbol{C} \times D \times E \times \boldsymbol{G2_B} \times I)$

## GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A1 | GHG reduction from using electric off-road agricultural equipment | [ ] | MT $CO_2e$ | calculated |
| A2 | GHG reduction from using hybrid off-road agricultural equipment | [] | MT $CO_2e$ | calculated |
| User Inputs | | | | |
| **B** | Fuel type of existing equipment | [ ] | text | user input |
| **C** | Hours of equipment operation | [ ] | hours | user input |
| **G2** | Carbon intensity of fossil fuel off-road equipment | [ ] | g $CO_2e$/hp-hour | CARB 2021; CAPCOA 2023 |
| Constants, Assumptions, and Available Defaults | | | | |
| D | Horsepower of electric or hybrid off-road equipment | [ ] | hp | user input; CARB 2023; CA CORE 2023 |
| E | Percent fuel reduction of hybrid equipment compared to conventional equipment | 10 | % | Holian and Pyeon 2017 |
| F | Conversion from horsepower to MW | 0.0007457 | MW/hp | conversion |
| G1 | Carbon intensity of local utility | See Table E-4.3 and Table E-4.4 (Handbook) | lbs $CO_2e$/MWh | CAPCOA 2021 |
| H | Conversion from lb to MT | 0.000454 | MT/lbs | conversion |
| I | Conversion from g to MT | $1 \: x \: 10^{-6}$ | MT/gram | conversion |

Further explanation of key variables:

- $(B)$ – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (G2) from OFFROAD.
- $(C)$ – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- $(D)$ – The horsepower of the electric agricultural equipment that is electric will need to be provided by the user.

- ($E$) – The percent fuel reduction is used in this formula as a proxy for the percent activity reduction that would be expected with hybrid, off-road, heavy-duty equipment. Based on a survey of 12 models of off-road, heavy-duty equipment from 10 different manufacturers, hybrid off-road equipment reduced fuel use by 10 to 45 percent, with an average of 28 percent (Holian and Pyeon 2017). To be conservative, the low end of the range is cited. If the user can provide an equipment-specific hp, the user should replace the default in the GHG calculation formula. If the user knows the make and model of the agricultural equipment used, the user should replace the default in the GHG calculation formula.
- ($F$) – Conversion factor assumes that energy requirements and losses are the same for both a fuel-powered engine and an electrically-charged engine.
- ($G1$) – GHG intensity factors for major California utilities are provided in Tables T-13.1 and T-13.2 in Appendix B of the Handbook. If the project study area is not serviced by a listed utility, or the user is able to provide a project-specific value (i.e., for the future year not referenced in Appendix B), the user should replace the default in the GHG calculation formula. If the utility is not known, the user may elect to use the statewide grid average carbon intensity.
- *(G2*) – GHG intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model. Note that the OFFROAD emissions rates are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor. In addition, GHG intensity factors for various off-road equipment can be obtained from the *User Guide for CalEEMod*: *Appendix G*.

## GHG Calculation Caps or Maximums

None.

## Example GHG Reduction Quantification

The user reduces agricultural equipment emissions by replacing fossil-fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example, an agricultural farm is replacing a 2020 model year 70-hp diesel tractor ($D$) that is used 8 hours per day ($C$) with an electric-powered equivalent (CARB 2023; CA CORE 2023). A 2020 model year 70-hp diesel tractor has an approximate carbon intensity of 530 grams $CO_2$e per hp-hour ($G2$). The electric utility for the project area is Pacific Gas & Electric Company, and the analysis year is 2025. The carbon intensity of electricity is, therefore, 206 lbs $CO_2$e per megawatt-hour ($G1$).

$$\mathrm{A} = \left(\mathbf{8}\ \frac{\mathbf{hours}}{\mathbf{day}} \times 70\ \mathrm{hp} \times 0.0007457\ \frac{\mathrm{MW}}{\mathrm{hp}} \times 206\ \frac{\mathrm{lbs\ CO2e}}{\mathrm{MWh}} \times 0.000454 \frac{\mathrm{MT}}{\mathrm{lb}}\right) - \left(\mathbf{8}\ \frac{\mathbf{hours}}{\mathbf{day}} \times 70\ \mathrm{hp} \times \mathbf{530}\ \frac{\mathbf{g\ CO2e}}{\mathbf{hp{-}hour}} \times 1\mathrm{x}10^{-6} \frac{\mathrm{MT}}{\mathrm{g}}\right) = -0.26\ \frac{\mathrm{MT\ CO2e}}{\mathrm{day}}$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, improved public health, improved ecosystem health, enhanced energy security, and social equity. This section defines the methods for quantifying improved air quality and energy and fuel savings.

### Improved Air Quality

Local criteria pollutants will be reduced by the reduction in fossil fuel combustion. Emission savings can be calculated using the same formula used to quantify GHG reductions (*A1* and *A2*). Criteria pollutant intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model.

Electricity supplied by statewide fossil-fueled power plants will generate criteria pollutants. However, because these power plants are located throughout the state, electricity consumption from equipment charging will not generate localized criteria pollutant emissions at the equipment source. Consequently, for the quantification of criteria pollutant emission reductions, either the electricity portion of the equation can be removed, or the electricity intensity (*G1*) can be set to zero.

### Energy and Fuel Savings

Fossil fuel savings are a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

Increased electricity consumption for electric equipment is calculated as part of the GHG reduction formula (*A*). The abbreviated formula is also shown below.

$$MWh = \boldsymbol{C} \times D \times F$$

## Sources

California Air Pollution Control Officer's Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2*. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

California Air Pollution Control Officer's Association (CAPCOA). 2023. *User Guide for CalEEMod Version 2022.1: Appendix G, Default Data Tables* Available: https://caleemod.com/user-guide. Accessed: January 2024.

California Air Resources Board (CARB). 2021. *OFFROAD2021–ORION*. Available: https://arb.ca.gov/emfac/emissions-inventory. Accessed: December 2023.

California Air Resources Board (CARB). 2023. *CARB Advanced Clean Off-Road Equipment List Fact Sheet*. Available: https://ww2.arb.ca.gov/sites/default/files/classic/ZEE/2023%20ZEE%20List%2008182023%20CORE%20TRL%20No%20Hybrid.pdf. Accessed: December 2023.

Clean Off-Road Equipment Voucher Incentive Project (CA CORE). 2023. *Eligible Equipment Catalog*. Available: https://californiacore.org/equipmentcatalog/. Accessed: December 2023.

Holian, M., and J. Pyeon. 2017. *Analyzing the Potential of Hybrid and Electric Off-Road Equipment in Reducing Carbon Emissions from Construction Industries*. Mineta Transportation Institute. Available: https://transweb.sjsu.edu/research/Analyzing-Potential-Hybrid-and-Electric-Road-Equipment-Reducing-Carbon-Emissions-Construction-Industries. Accessed: December 2023.

# Miscellaneous

The Miscellaneous sector in the Handbook is comprised of three quantified measures that involve less-specific means of reducing GHG emissions, such as establishing a carbon sequestration or off-site mitigation project. This memorandum presents an additional measure for the Miscellaneous sector; however, the potential new measure involves a more specific reduction pathway than the other measures. MSIC-1 is similar to measures from the Construction sector in the Handbook that pertain to cleaner construction equipment, but it involves improving off-road equipment more generally. As such, ICF believes that the measure is most appropriate to include in the Miscellaneous sector because no other sectors in the Handbook are applicable to this measure.

## M-6. Off-Road Equipment Efficiency

### Description

This measure requires use of electric- or hybrid-powered off-road equipment over conventional diesel-fueled counterparts during operational activities. Replacing diesel-powered off-road equipment with electric or hybrid-electric equipment reduces fossil fuel combustion and thus GHG emissions. However, all-electric equipment results in GHG emissions from the electricity used to charge the equipment. The indirect GHG emissions increase from electricity must be calculated in addition to the GHG emissions reduction from displaced fossil fuel combustion to estimate the total net GHG emissions reduction achieved by this measure if using electric equipment.

### Scale of Application

All - Project/Site and Plan/Community

### GHG Reduction Formula

$$A1 = (\boldsymbol{C} \times D \times F \times G1 \times H) - (\boldsymbol{C} \times D \times \boldsymbol{G2_B} \times I)$$

$$A2 = (\boldsymbol{C} \times D \times E \times \boldsymbol{G2_B} \times I)$$

### GHG Calculation Variables

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Output | | | | |
| A1 | GHG reduction from using electric off-road equipment | [ ] | MT $CO_2e$ | calculated |
| A2 | GHG reduction from using hybrid off-road equipment | [] | MT $CO_2e$ | calculated |
| User Inputs | | | | |
| **B** | Fuel type of existing equipment | [ ] | text | user input |
| **C** | Hours of equipment operation | [ ] | hours | user input |
| **G2** | Carbon intensity of fossil fuel off-road equipment | [ ] | g $CO_2e$/hp-hour | CARB 2021; CAPCOA 2023 |

| ID | Parameter | Value | Unit | Source |
|---|---|---|---|---|
| Constants, Assumptions, and Available Defaults | | | | |
| D | Horsepower of electric or hybrid off-road equipment | [ ] | hp | user input; CARB 2023; CA CORE 2023 |
| E | Percent fuel reduction of hybrid equipment compared to conventional equipment | 10 | % | Holian and Pyeon 2017 |
| F | Conversion from horsepower to MW | 0.0007457 | MW/hp | conversion |
| G1 | Carbon intensity of local utility | See Table E-4.3 and Table E-4.4 (Handbook) | lbs $CO_2e$/MWh | CAPCOA 2021 |
| H | Conversion from lb to MT | 0.000454 | MT/lbs | conversion |
| I | Conversion from g to MT | $1\ x\ 10^{-6}$ | MT/gram | conversion |

Further explanation of key variables:

- ($B$) – The fuel type of the existing equipment is used to obtain the carbon intensity of the equipment (G2) from OFFROAD.
- ($C$) – This input represents the hours of operation that the equipment will be used over a user-specified time period.
- ($D$) – The horsepower of the electric off-road equipment that is electric or hybrid will need to be provided by the user.
- ($E$) – The percent fuel reduction is used in this formula as a proxy for the percent activity reduction that would be expected with hybrid off-road heavy-duty equipment. Based on a survey of 12 models of off-road heavy-duty equipment from 10 different manufacturers, hybrid off-road equipment reduced fuel use by 10 to 45 percent, with an average of 28 percent (Holian and Pyeon 2017). To be conservative, the low end of the range is cited. If the user can provide an equipment-specific hp, the user should replace the default in the GHG calculation formula. If the user knows the make and model of the off-road equipment used, the user should replace the default in the GHG calculation formula.
- ($F$) – Conversion factor assumes that energy requirements and losses are the same for both a fuel-powered engine and an electrically-charged engine.
- ($G1$) – GHG intensity factors for major California utilities are provided in Tables T-13.1 and T-13.2 in Appendix B of the Handbook. If the project study area is not serviced by a listed utility, or the user is able to provide a project-specific value (i.e., for the future year not referenced in Appendix B), the user should replace the default in the GHG calculation formula. If the utility is not known, the user may elect to use the statewide grid average carbon intensity.
- ($G2$) – GHG intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model or from the California Emission Estimator Model (CalEEMod) User Guide. Note that the OFFROAD emissions rates are inclusive of equipment load. Therefore, the GHG reduction equation does not include a multiplier for load factor. In addition, GHG intensity factors for various off-road equipment can be obtained from the *User Guide for CalEEMod*: *Appendix G*.

## GHG Calculation Caps or Maximums

None.

## Example GHG Reduction Quantification

The user reduces off-road equipment emissions by replacing fossil-fuel combustion with electricity consumption, which generates fewer GHG emissions per unit of activity. In this example, a Port is replacing a 2020 model year 575-hp diesel reach stacker forklift (*D*) that is used 8 hours per day (*C*) with an electric-powered equivalent (CARB 2023; CA CORE 2023). A 2020 model year 575-hp diesel reach stacker forklift has an approximate carbon intensity of 531 grams $CO_2e$ per hp-hour (*G2*). The electric utility for the project area is Pacific Gas & Electric Company, and the analysis year is 2025. The carbon intensity of electricity is, therefore, 206 lbs $CO_2e$ per megawatt-hour (*G1*).

$$\mathrm{A} = \left(\mathbf{8}\ \frac{\mathbf{hours}}{\mathbf{day}} \times 575\ \mathrm{hp} \times 0.0007457\ \frac{\mathrm{MW}}{\mathrm{hp}} \times 206\ \frac{\mathrm{lbs\ CO2e}}{\mathrm{MWh}} \times 0.000454 \frac{\mathrm{MT}}{\mathrm{lb}}\right) - \left(\mathbf{8}\ \frac{\mathbf{hours}}{\mathbf{day}} \times 575\ \mathrm{hp} \times \mathbf{531}\ \frac{\mathbf{g\ CO2e}}{\mathbf{hp-hour}} \times 1\mathrm{x}10^{-6} \frac{\mathrm{MT}}{\mathrm{g}}\right) = -2.12\ \frac{\mathrm{MT\ CO2e}}{\mathrm{day}}$$

## Measure Co-Benefits

Successful implementation of this measure could achieve improved air quality, energy and fuel savings, improved public health, improved ecosystem health, enhanced energy security, and social equity. This section defines the methods for quantifying improved air quality and energy and fuel savings.

### Improved Air Quality

Local criteria pollutants will be reduced by the reduction in fossil fuel combustion. Emission savings can be calculated using the same formula used to quantify GHG reductions (*A1* and *A2*). Criteria pollutant intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model.

Electricity supplied by statewide fossil-fueled power plants will generate criteria pollutants. However, because these power plants are located throughout the state, electricity consumption from equipment charging will not generate localized criteria pollutant emissions at the equipment source. Consequently, for the quantification of criteria pollutant emission reductions, either the electricity portion of the equation can be removed, or the electricity intensity (*G1*) can be set to zero.

### Energy and Fuel Savings

Fossil fuel savings are a product of the equipment fuel efficiency (gallons consumed per hour) and the equipment operating time (hours). Fuel intensity factors for various off-road equipment can be obtained from CARB's (2021) OFFROAD model. Users should multiply the fuel intensity by the equipment operating hours to quantify fuel savings.

Increased electricity consumption for electric equipment is calculated as part of the GHG reduction formula (*A*). The abbreviated formula is also shown below.

$$MWh = \boldsymbol{C} \times D \times F$$

## Sources

California Air Pollution Control Officer's Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2*. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

California Air Pollution Control Officer's Association (CAPCOA). 2023. *User Guide for CalEEMod Version 2022.1: Appendix G, Default Data Tables.* Available: https://caleemod.com/user-guide. Accessed: January 2024.

California Air Resources Board (CARB). 2021. *OFFROAD2021–ORION*. Available: https://arb.ca.gov/emfac/emissions-inventory. Accessed: December 2023.

California Air Resources Board (CARB). 2023. *CARB Advanced Clean Off-Road Equipment List Fact Sheet*. Available: https://ww2.arb.ca.gov/sites/default/files/classic/ZEE/2023%20ZEE%20List%2008182023%20CORE%20TRL%20No%20Hybrid.pdf. Accessed: December 2023.

Clean Off-Road Equipment Voucher Incentive Project (CA CORE). 2023. *Eligible Equipment Catalog*. Available: https://californiacore.org/equipmentcatalog/. Accessed: December 2023.

Holian, M., and J. Pyeon. 2017. *Analyzing the Potential of Hybrid and Electric Off-Road Equipment in Reducing Carbon Emissions from Construction Industries*. Mineta Transportation Institute. Available: https://transweb.sjsu.edu/research/Analyzing-Potential-Hybrid-and-Electric-Road-Equipment-Reducing-Carbon-Emissions-Construction-Industries. Accessed: December 2023.

# APPENDIX A–Data Tables

### Table T-40.1. Average Student Occupancy of School Buses

| Location | Average Student Occupancy of School Buses (students per bus) |
|---|---|
| San Francisco Bay Area | 10.1 |
| Los Angeles, Orange County, and Long Beach | 17.3 |
| San Diego | 14.9 |
| California Average | 9.3 |

Source: Wang, Y., R. Mingo, J. Lutin, W. Zhu, and M. Zhu. 2019. *Developing a Statistically Valid and Practical Method to Compute Bus and Truck Occupancy Data*. Federal Highway Administration. Available: https://www.academia.edu/64325343/Developing_a_Statistically_Valid_and_Practical_Method_to_Compute_Bus_and_Truck_Occupancy_Data. Accessed: December 2023.

### Table T-40.2. California School Bus Emission Factors by Fuel Type

| Fuel Type | Fuel Efficiency | | Energy Density | | Carbon Intensity | | Emission Factor [e] (g $CO_2e$/mile) |
|---|---|---|---|---|---|---|---|
| | Value | Units | Value | Units | Value | Units | |
| Gasoline | 9.42[a] | miles/ gallon (mpg) | 115.8[b] | Mega Joule (MJ)/gallon | 93.2[b] | grams $CO_2e$/Mega Joule (g $CO_2e$/MJ) | 1145.7 |
| Diesel | 7.92[a] | mpg | 134.5[b] | MJ/gallon | 94.2[b] | g $CO_2e$/MJ | 1599.7 |
| Electricity | 1.1[a] | kWh/mile | 3.6[c] | MJ/kWh | 93.8[c] | g $CO_2e$/MJ | 371.4 |
| Natural Gas | 4.48[a] | mpg-diesel equivalent | 134.5[b] | MJ/gallon | 32.7[d] | g $CO_2e$/MJ | 981.7 |

Sources:

[a] California Air Resources Board. 2021. EMFAC2021. Available: https://arb.ca.gov/emfac/emissions-inventory/5fe430c4465c4fa60d41f578fbaefa5c758b58ef. Accessed: December 2023.

[b] Gasoline value reflects California Reformulated Gasoline (RFG), which consists of a blend of California Reformulated Gasoline Blendstock for Oxygenate Blending (CARBOB) and 10 percent ethanol. Source: California Air Resources Board. 2020b. *Unofficial electronic version of the Low Carbon Fuel Standard Regulation*. Available: https://ww2.arb.ca.gov/sites/default/files/2020-07/2020_lcfs_fro_oal-approved_unofficial_06302020.pdf. Accessed: December 2023.

[c] California Air Resources Board. 2020c. *California Climate Investments Quantification Methodology Emission Factor Database and Documentation*. Available: https://ww2.arb.ca.gov/resources/documents/cci-quantification-benefits-and-reporting-materials. Accessed: December 2023.

[d] California Air Resources Board. 2019. *LCFS Pathway Certified Carbon Intensities*. Available: https://ww2.arb.ca.gov/resources/documents/lcfs-pathway-certified-carbon-intensities. Accessed: December 2023.

[e] Where fuel efficiency is measured in miles per gallon, the emission factor is calculated as (fuel efficiency * energy density * carbon intensity). Where fuel efficiency is measured in kilowatt-hours per mile, the emission factor is calculated as ([1/fuel efficiency] * energy density * carbon intensity).

### Table E-21.1. Cool Pavement Maximum Yearly Electricity Savings

| EDFZ Zone | Cooling Savings (kWh/m²/year)[a] |
|---|---|
| 4 | 0.8 |
| 5 | 0.1 |
| 7 | 1.2 |
| 11 | 0.9 |
| 12 | 0.8 |
| 16 | 0.2 |
| 17 | 1.2 |
| 18 | 1.6 |

Sources: Lawrence Berkely National Laboratory. 2017a. *Are Cooler Surfaces a Cost-Effect Mitigation of Urban Heat Islands?* Available: https://eta-publications.lbl.gov/sites/default/files/cooler_surfaces.pdf. Accessed: August 2023.

Lawrence Berkely National Laboratory. 2017b. *Energy and Environmental Consequences of a Cool Pavement Campaign*. Available: https://eta-publications.lbl.gov/sites/default/files/e-b-cool-pavement-campaign.pdf. Accessed: August 2023.

EDFZ = Electricity Demand Forecast Zone, kWh = kilowatt-hour, $m^2$ = square meters.

[a.] An average Cooling Savings was calculated for cities that were in the same EDFZs.

### Table E-26.1. Capacity Factors for Biomass Electricity Generation in the United States

| Fuel Type | Capacity Factor [a] |
|---|---|
| Other Biomass [b] | 62% |
| Wood | 59% |

Source: U.S. Energy Information Agency (U.S. EIA). 2023. *Table 6.07.B. Capacity Factors for Utility Scale Generators Primarily Using Non-Fossil Fuels. Electric Power Monthly*. Available: *https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=table_6_07_b.* Accessed: December 2023.

[a] Capacity factors are based on an average of the last 5 years of generation.

[b] Other biomass includes landfill gas, non-biogenic municipal solid waste, sludge waste, biogenic municipal solid waste, black liquor, and agricultural byproducts.

### Table E-26.2. Lifecycle Emission Factors for Biomass Electricity Generation in the United States

| Fuel Type | Life Cycle GHG Emission Factors (lbs $CO_2e$/MWh)[a] | | |
|---|---|---|---|
| | Mean | Median | Standard Deviation |
| Dedicated Woody Crops | 189.6 | 114.7 | 308.7 |
| Dedicated Herbaceous Crops | 617.4 | 119.1 | 882 |
| Agricultural Residues | 573.3 | 123.5 | 882 |
| Forest Residues | 374.8 | 79.4 | 683.6 |
| Urban Residues | 904.1 | 108 | 859.9 |
| Mill Residues | 202.9 | 33.1 | 485.1 |
| Animal Wastes & Processing Residues | 1,367.1 | 286.6 | 859.9 |
| Other Wastes & Residues | 132.3 | 92.6 | 108 |

Source: Electric Power Research Institute (EPRI). 2013. *Literature Review and Sensitivity Analysis of Biopower Life-Cycle Assessments and Greenhouse Gas Emissions.* Available: https://www.epri.com/research/products/1026852. Accessed: December 2023.

[a] Emission factors exclude the effects of land use change. Use the mean value.

**Table S-3.1. Solid Waste Emission Factors**

| Food Waste Prevention [a] | | |
|---|---|---|
| **Refrigeration & Freezer Equipment - Energy Consumption [b]** | **Emission Reduction Factor** | **Unit** |
| Food waste prevention | 1.78 | $MTCO_2e$/short ton feedstock |
| Residential Refrigerator/Freezer Combination | 8.46 | kWh/year/ft$^3$ of volume |
| | 335.7 | kWh/year |
| Residential Freezer Only | 7.85 | kWh/year/ft$^3$ of volume |
| | 172.3 | kWh/year |
| Residential Refrigerator Only | 7.28 | kWh/year/ft$^3$ of volume |
| | 206.7 | kWh/year |
| Commercial Refrigerator with solid doors or Walk-in Commercial Refrigerator with Solid Doors | 36.5 | kWh/year/ft$^3$ of volume |
| | 744.6 | kWh/year |
| Commercial Refrigerator with transparent doors or Walk-in Commercial Refrigerator with Transparent doors | 43.8 | kWh/year/ft$^3$ of volume |
| | 1,219.1 | kWh/year |
| Commercial Freezer with solid doors or Walk-in Commercial Freezer with Solid Doors | 146.0 | kWh/year/ft$^3$ of volume |
| | 503.7 | kWh/year |
| Commercial Freezer with transparent doors or Walk-in Commercial Freezer with transparent doors | 273.8 | kWh/year/ft$^3$ of volume |
| | 1,496.5 | kWh/year |
| Commercial Refrigerator/freezer with solid doors or Walk-in Commercial Refrigerator/freezer with solid doors | 98.6 | kWh/year/ft$^3$ of volume |
| | -259.2 | kWh/year |
| | 255.5 | minimum value kWh/year |

| Refrigerant Leakage Assumptions [c] | Average Annual Leak Rate | Unit |
|---|---|---|
| Residential Refrigerator/Freezer Combination | 1% | % |
| Residential Freezer Only | 1% | % |
| Residential Refrigerator Only | 1% | % |
| Commercial Refrigeration systems with charge < 50 lbs | 15.0% | % |
| Commercial Refrigeration systems with charge 50 lbs to < 200 lbs | 15.0% | % |
| Commercial Refrigeration systems with charge 200 lbs to < 2,000 lbs | 17.6% | % |
| Commercial Refrigeration systems with charge ≥ 2,000 lbs | 16.6% | % |
| Transportation Vehicle | 24.0% | % |

| Default Refrigerant Charge Sizes [c] | Average Annual Leak Rate | Unit |
|---|---|---|
| Residential refrigerators/freezers and chest freezers | 0.34 | lbs |
| Commercial Refrigerator/Freezers | 7.10 | lbs |
| Small Walk In Refrigerator/Freezer | 31.40 | lbs |
| Large Walk In Refrigerator/Freezer | 122.00 | lbs |
| Refrigerated Van | 4.00 | lbs |
| Refrigerated Box Truck | 12.00 | lbs |
| Refrigerated Heavy Duty Truck | 22.00 | lbs |

| Supported Delivery Vehicle Types [d] | |
|---|---|
| **Vehicle Category** | **Fuel Type** |
| LDA | Gasoline |
| | Gasoline hybrid |
| | Flex fuel (E85) |
| | PHEV10 |
| | BEV |
| LDT1 | Gasoline |
| | Gasoline hybrid |
| | Flex fuel (E85) |
| | PHEV10 |
| | BEV |
| LDT2 | Gasoline |
| | Diesel |
| MDV | Gasoline |
| | Diesel |
| LHDT1 | Gasoline |
| | Diesel |
| | BEV |
| LHDT2 | Gasoline |
| | Diesel |
| | BEV |
| MHDT | Gasoline |
| | Composite Diesel |
| | BEV |
| HHDT | Composite Diesel |
| | Natural gas |
| | BEV |

Sources:

[a.] Venkat, K. 2012. *The Climate Change and Economy Impacts of Food Waste in the United States.* International Journal on Food System Dynamics 2(4): 431-446. Available: https://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf. Accessed: December 2023.

[b.] Code of Federal Regulations. 2023. *10 CFR 431.66 – Energy Conservation standards and their effective dates.* Available: https://www.ecfr.gov/current/title-10/chapter-II/subchapter-D/part-431/subpart-C/subject-group-ECFR8115bf7451f830f/section-431.66. Accessed December: 2023.

[c.] California Air Resources Board. 2016. *California's High Global Warming Potential Gases Emission Inventory*: *Emission Inventory Methodology and Technical Support Document.* April. Available: https://ww2.arb.ca.gov/sites/default/files/classic/cc/inventory/slcp/doc/hfc_inventory_tsd_20160411.pdf. Accessed: December 2023.

[d.] California Air Pollution Control Officers Association (CAPCOA). 2021. *Handbook for Analyzing Greenhouse Gas Emissions Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity: Appendix C – Table T-30.2*. Available: https://www.airquality.org/ClimateChange/Documents/Final%20Handbook_AB434.pdf#page=661. Accessed: December 2023.

LDA = light-duty automobile; light-duty truck 1 (LDT1); light-duty truck 2 (LDT2); MDV = medium-duty vehicle; light-heavy duty truck 1 (LHDT1); light-heavy duty truck 2 (LHDT2); MHDV = medium-heavy duty vehicle; HHDV =

heavy-heavy duty vehicle; MJ = megajoules; mpg = miles per gallon; mpgde = miles per gallon of diesel equivalent; gal = gallon; kWh = kilowatt-hours; $CO_2e$ = carbon dioxide equivalent; g = grams

### Table S-3.2. Solid Waste Emission Factors

| Grid Electricity Emission Factors [a] | | |
|---|---|---|
| **Product** | **Emission Reduction Factor** | **Unit** |
| ROG Electricity Emission Factor | 0.000021 | lbs/kWh |
| NOx Electricity Emission Factor | 0.000131 | lbs/kWh |
| PM2.5 Electricity Emission Factor | 0.000033 | lbs/kWh |
| **Food Waste Prevention - Avoided Food Transportation [a, b]** | | |
| ROG Avoided Transportation Emission Factor | 0.016 | lbs/short ton of food waste |
| NOx Avoided Transportation Emission Factor | 0.299 | lbs/short ton of food waste |
| PM2.5 Avoided Transportation Emission Factor | 0.009 | lbs/short ton of food waste |
| Diesel PM Avoided Transportation Emission Factor | 0.001 | lbs/short ton of food waste |

Sources:

[a]. California Air Resources Board. 2020. *Benefits Calculator Tool for the Food Waste Prevention and Rescue Program*. Available: https://ww2.arb.ca.gov/sites/default/files/auction-proceeds/calrecycle_finalfoodcalc_19-20.xlsx. Accessed: August 2023.

[b]. Venkat, K. 2012. *The Climate Change and Economy Impacts of Food Waste in the United States.* International Journal on Food System Dynamics 2(4): 431-446. Available: https://www.cleanmetrics.com/pages/ClimateChangeImpactofUSFoodWaste.pdf. Accessed: December 2023.

ROG = reactive organic gases; $NO_X$ = nitrous oxides; $PM_{2.5}$ = fine particulate matter; PM = particulate.