Appendix C

Landfill Methane Emissions Methodology

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I. Waste

A. Landfills (IPCC 4A1)

1. <u>Background</u>

Landfills are sites for solid waste disposal in which refuse is buried between layers of dirt so as to fill in or reclaim low-lying ground or excavated pits; they are the oldest form of waste treatment. There are numerous types of landfills accepting different types of waste. The GHG inventory is concerned only with landfills that contain and/or receive biodegradable, carbon-bearing waste. The California Integrated Waste Management Board (CIWMB) has identified 372 such landfills in the State. Most of the waste contained in these landfills (94 percent) is currently under some form of control that reduces the emissions of methane, the principal GHG pollutant generated by landfills.

Landfilled carbon-bearing waste degrades mainly through anaerobic biodegradation. In an anaerobic environment (i.e., without oxygen from the air), water (H_2O) is the source of oxygen (O) for oxidation and becomes the limiting reactant for biodegradation. The water content of a landfill determines how fast the waste degrades. If water is not available, the waste does not degrade. This anaerobic biodegradation process generates approximately equal amounts of CO_2 and CH_4 gas as a byproduct:

Equation 1: Anaerobic biodegradation process

$$2C + 2H_2O \rightarrow CO_2 + CH_4$$

A large fraction (57 percent to 66 percent) of the waste will not degrade under these anaerobic conditions and the carbon it contains is effectively sequestered. This carbon will remain sequestered as long as the landfill’s anaerobic conditions persist.

The various gases produced as the waste degrades are collectively called “landfill gas”. Landfill gas is an odor nuisance, a source of air toxics and may even be a physical danger to those living near a landfill because the methane it contains is combustible. For these reasons, most landfills in the State (holding over 95% percent) of the waste) are equipped with a gas collection system. However, although those collection systems are designed to collect landfill gas, it is known that a portion of the gas does escape into the atmosphere.

Once collected, landfill gas can simply be vented to the air if the only reason for the collection was to address offsite gas migration issues. Alternatively, the collected landfill gas may be stripped of its non-methane components via carbon adsorption, which main purpose is to reduce odors and/or volatile organic compounds (VOC) and toxics. Carbon adsorption allows most (99 percent) of the CH_4 to escape. Most commonly, the collected landfill gas is combusted, either in a flare (to destroy odors and VOC and toxic components in the gas, or in an engine or turbine to generate electricity.

2. Methodology

ARB staff requested site-specific landfill gas collection data through landfill surveys, but received answers for only certain years and for less than half of the landfilled waste (e.g., approximately 42 percent in 2005). Therefore, staff opted to use a model to estimate landfill emissions for all sites, and used the survey data to supplement these predictions where available.

Staff used the Mathematically Exact First-Order Decay (FOD) model from the 2006 Intergovernmental Panel on Climate Change (IPCC) Guidelines (IPCC, 2006b). In summary, this model assumes that a fixed fraction of the waste available at any moment will degrade. The amount that degrades over a given amount of time is determined by a factor (*k*), which is tied to the moisture content in the landfill. The *k* values used in the model were obtained from USEPA and are function of the annual precipitation occurring at each landfill; rainfall being used as a surrogate for landfill moisture content. The model assumes that the waste carbon is biodegraded into equal amounts of CO_2 and CH_4 (see Equation 1).

2.1 Model Equations

The inputs to the model are the amount of anaerobically degradable organic carbon (ANDOC), the delay in months before waste begins to decay anaerobically (*M*), the rate at which waste decays (*k*), and the fraction of degraded carbon that is converted into $_{CH4}$ (F_{CH4}). Of these four inputs, three are set by using default values: a six month default for *M*, a 50 percent default for F_{CH4} and USEPA defaults based on rainfall levels for *k*. Only *ANDOC* requires a more detailed method of derivation, which is the focus equation 1 below. The inputs for calculating *ANDOC* are therefore important determinants of landfill emissions estimates.

(a) Anaerobically Degradable Organic Carbon (*ANDOC*)

Equation 2: Anaerobically degradable organic carbon

$$ANDOC = WIP \bullet 0.9072 \bullet \sum_{component} (FW_{component} \bullet DOC_{component} \bullet DANF_{component})$$

Where,

ANDOC	= Anaerobically Degradable Organic Carbon: the amount of waste carbon that is biodegradable in an anaerobic environment (Mg (i.e., 10^6 grams) of carbon)
WIP	= Waste-in-Place: the landfilled waste (wet weight) as reported to the California Integrated Waste Management Board (tons)
0.9072	= Short ton to Mg (a.k.a. tonne or metric ton) conversion
$FW_{component}$	= Fraction of a given waste component in the landfilled waste
$DOC_{component}$	= Degradable Organic Carbon (DOC) content of the given waste component.
$DANF_{component}$	= Decomposable Anaerobic Fraction (DANF) of the given waste component.

With,

Component	= [Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, Branches, Lumber, Textiles, Diapers, Construction/Demolition, Medical Waste, Sludge/Manure]

(a.i) Waste-In-Place (WIP)

The California Integrated Waste Management Board (CIWMB) staff provided ARB staff with Waste-in-Place (*WIP*) data in two basic forms: 1) the cumulative amount of waste deposited, by landfill, up to the year 1990 and, 2) the amounts deposited, by landfill, each year from 1991 to 2005 for those landfills still receiving waste after 1990. CIWMB staff also furnished the amounts of green waste and sludge used as daily cover by each landfill from 1995 to 2005. CIMWB staff provided data on 372 landfills known to contain waste that is biodegradable. Landfills containing only inert waste, like ash and masonry from demolition sites, were excluded. ARB staff also received survey data from 30 of these landfills (comprising 41.8% percent of the 2005 WIP) and used them to update the CIWMB data. In most cases, however, these updates were modest.

Yearly amounts of deposited waste are necessary inputs for the IPCC FOD model to work properly. Yearly data were not available before 1990, however, only the cumulative WIP totals in 1990 were known. This led staff to estimate how much of these cumulative amounts were deposited each year from the landfills' opening year to 1990 (or up to their closure year if they closed before 1990). This estimation was made as follows. First, ARB staff inquired about the opening and closure dates for all landfills. CIWMB staff had closure dates for all 372 landfills of interest, but did not have a complete list of opening dates, so an estimate was made for those cases where the opening date was missing. Once these dates were established, the cumulative total of WIP in each landfill was distributed over the pre-1990 years (from opening to 1990, or opening to closure if before 1990) in a manner commensurate to the trend in California's population over those years. As a result, a larger proportion of the waste in place was distributed in the later years of this range than in the earlier ones, since the population kept growing over the time period.

(a.ii) Components of the Waste-in-Place

To determine its DOC and DANF, the WIP must first be disaggregated into its component parts. Disaggregation was done on the basis of waste characterization studies from the CIWMB and the USEPA. The CIWMB studies were conducted in 1999 and 2004; the1999 study was used to characterize waste for 1995 to 2002 and the 2004 study for 2003 and beyond, as suggested by the CIWMB staff. For years prior to 1995, staff used the USEPA study that best applied to a given year. The USEPA did waste characterization studies in 1960, 1970, 1980 and 1990. Staff used the waste profiles from those studies as follows: up to 1964 (1960 survey), 1965-1974 (1970 survey), 1975-1984 (1980 survey) and 1985-1994 (1990 survey). Applying these profiles allowed disaggregating the waste deposited each year into its component parts. The components of interest to estimate TDOC (i.e., those containing biodegradable carbon content) are listed in Table 1.

Table 1: Waste characterization – Percentage of each component in the overall waste in place

Waste Component	***Up to 1964***	***1965 - 1974***	***1975 - 1984***	***1985 - 1994***	***1995 - 2002***	***2003+***
Newspaper	*6.4%*	*6.4%*	*5.9%*	*4.8%*	*4.3%*	*2.2%*
Office Paper	*7.4%*	*8.2%*	*11.6%*	*12.5%*	*4.4%*	*2.0%*
Corrugated Boxes	*13.8%*	*16.2%*	*11.4%*	*10.6%*	*4.6%*	*5.7%*
Coated Paper	*2.5%*	*2.4%*	*2.9%*	*2.5%*	*16.9%*	*11.1%*
Food	*14.8%*	*11.3%*	*9.5%*	*12.1%*	*15.7%*	*14.6%*
Grass	*12.1%*	*10.3%*	*10.1%*	*9.0%*	*5.3%*	*2.8%*
Leaves	*6.1%*	*5.1%*	*5.0%*	*4.5%*	*2.6%*	*1.4%*
Branches	*6.1%*	*5.1%*	*5.0%*	*4.5%*	*2.4%*	*2.6%*
Lumber	*3.7%*	*3.3%*	*5.1%*	*7.0%*	*4.9%*	*9.6%*
Textiles	*2.1%*	*1.8%*	*1.7%*	*4.0%*	*2.1%*	*4.4%*
Diapers	*0.1%*	*0.3%*	*1.4%*	*1.6%*	*6.9%*	*4.4%*
Construction/Demolition	*2.6%*	*2.5%*	*3.5%*	*3.9%*	*6.7%*	*12.1%*
Medical Waste	-	-	-	-	*0.0%*	*0.0%*
Sludge/Manure	-	-	-	-	*0.1%*	*0.1%*

* Dash indicates no data available; percentage assumed to be zero.

The combined amounts of green waste and sludge used as daily cover were included with landfills WIP. According to CIWMB staff, most of the daily cover is green waste, thus ARB staff assumed that 10% of the daily cover amounts were percent sludge and 90 percent green waste. Green waste was further categorized as 50% grass cuttings, 25% leaves and 25% branches, based on USEPA studies (Table 2) Green waste was further split based on USEPA study assumptions that 50 percent is Grass, 25 percent Leaves and 25 percent Branches.

Table 2: Waste characterization of daily cover material

Daily Cover Waste Component	***Assumed Content Percentage***
Sludge/Manure	*10%*
Grass	*45%*
Leaves	*22.5%*
Branches	*22.5%*

(a.iii) Degradable Organic Carbon (DOC) content

Staff obtained values for the Degradable Organic Carbon (DOC) content of solid waste components from USEPA (Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, Branches) and from the 2006 IPCC Guidelines (Lumber, Textiles, Diapers, Construction/Demolition, Medical Waste, Sludge/Manure). These values are summarized in Table 3.

Table 3: Degradable Organic Carbon (DOC) content of different MSW components

Waste Component	***DOC Fraction (Mg DOC / Mg wet waste)***	***Source***
Newspaper	*0.465*	*USEPA*
Office Paper	*0.398*	*USEPA*
Corrugated Boxes	*0.405*	*USEPA*
Coated Paper	*0.405*	*USEPA*
Food	*0.117*	*USEPA*
Grass	*0.192*	*USEPA*
Leaves	*0.478*	*USEPA*
Branches	*0.279*	*USEPA*
Lumber	*0.430*	*IPCC*
Textiles	*0.240*	*IPCC*
Diapers	*0.240*	*IPCC*
Construction/Demolition	*0.040*	*IPCC*
Medical Waste	*0.150*	*IPCC*
Sludge/Manure	*0.050*	*IPCC*

(a.iv) Decomposable Anaerobic Fraction (DANF)

Theoretically, all biodegradable carbon-bearing waste can degrade, but only a portion actually degrades in the special anaerobic environment of landfills. The carbon in the waste that does not decompose remains sequestered.

Values for the DANF of different MSW components came from USEPA (Newspaper, Office Paper, Corrugated Boxes, Coated Paper, Food, Grass, Leaves, and Branches), the CEC (lumber) and the IPCC guidelines (default of 50 percent anaerobic decomposition for Textiles, Diapers, Construction/Demolition, Medical Waste, and Sludge/Manure).

Table 4: Decomposable anaerobic fraction (DANF) of the DOC of different MSW components

Waste Component	***Decomposable Anaerobic Fraction***	***Source***
Newspaper	*0.161*	*USEPA*
Office Paper	*0.874*	*USEPA*
Corrugated Boxes	*0.383*	*USEPA*
Coated Paper	*0.210*	*USEPA*
Food	*0.828*	*USEPA*
Grass	*0.322*	*USEPA*
Leaves	*0.100*	*USEPA*
Branches	*0.176*	*USEPA*
Lumber	*0.233*	*CEC*
Textiles	*0.500*	*IPCC*
Diapers	*0.500*	*IPCC*
Construction/Demolition	*0.500*	*IPCC*
Medical Waste	*0.500*	*IPCC*
Sludge/Manure	*0.500*	*IPCC*

(a.v) Overall Waste Profile and Estimate of landfilled Carbon Sequestration

With the data described above, staff calculated the overall waste profile for California (Table 5). Staff also estimated the amount of non-decomposable organic carbon in landfills, that is, the carbon which is expected to remain sequestered until removed from the anaerobic conditions present in landfills (Table 6). Most of the waste in landfills is non-biodegradable. Of that portion that is biodegradable (19% to 24%) most will not decompose in a landfill environment and instead will remain permanently sequestered.

Table 5: Overall waste profile for California - Percentage of each component in the overall waste in place

Waste Type	***Up to 1964***	***1965 - 1974***	***1975 - 1984***	***1985 - 1994***	***1995 - 2002***	***2003+***
Biodegradable Carbon	*23.36%*	*22.96%*	*23.07%*	*23.54%*	*21.78%*	*19.00%*
▪ *Decomposable*	*8.85%*	*8.90%*	*9.47%*	*10.17%*	*7.81%*	*6.72%*
▪ *Sequestered*	*14.51%*	*14.06%*	*13.60%*	*13.37%*	*13.97%*	*12.28%*
Other Materials	*76.64%*	*77.04%*	*76.93%*	*76.46%*	*78.22%*	*81.00%*

Most of the waste in landfills is non-biodegradable. Of that portion that is biodegradable (19 percent to 24 percent) most will not decompose in a landfill environment and instead will remain permanently sequestered.

Table 6: Estimate of carbon sequestration in landfills (million metric tonnes of carbon)

Waste Component	***1990***	***2004***
Newspaper	*0.772*	*0.339*
Office Paper	*0.258*	*0.039*
Corrugated Boxes	*1.092*	*0.567*
Coated Paper	*0.330*	*1.400*
Food	*0.100*	*0.115*
Grass	*0.480*	*0.144*
Leaves	*0.793*	*0.238*
Branches	*0.424*	*0.235*
Lumber	*0.952*	*1.256*
Textiles	*0.198*	*0.210*
Diapers	*0.079*	*0.206*
Construction/Demolition	*0.032*	*0.095*
Medical Waste	-	*0.001*
Sludge/Manure	-	*0.001*
TOTAL	*5.51*	*4.85*

Note: comprehensive carbon sequestration estimates for all years 1990-2004 are available upon request.

(b) Change in ANDOC

Next, staff used the IPCC FOD model to calculate the change in ANDOC over time, determining how much of the anaerobically degradable organic carbon remains at the end of each year:

Equation 3: Change in anaerobically degradable organic carbon in landfills

$$ANDOCstock_{Year\,(i+1)} = \left\{ \begin{array}{l} ANDOCstock_{year\,(i)} \bullet e^{-k} \\ + ANDOCadded_{year\,(i-1)} \bullet [\frac{1}{k} \bullet (e^{-k \bullet [1-\frac{M}{12}]} - e^{-k}) - \frac{M}{12} \bullet e^{-k}] \\ + ANDOCadded_{year\,(i)} \bullet [\frac{1}{k} \bullet (1 - e^{-k \bullet [1-\frac{M}{12}]}) + \frac{M}{12}] \end{array} \right\}$$

Where,

$ANDOCstock_{Year(i+1)}$ = stock of ANDOC remaining un-decomposed at the end of inventory year i, and thus present in the landfill at the beginning of the next year (year i+1), (g)

$ANDOCstock_{Year(i)}$ = stock of ANDOC present in the landfill at the beginning of inventory year i, i.e., remaining un-decomposed at the end of the previous year (i-1), (g)

$ANDOCadded_{Year(i-1)}$ = ANDOC added during the previous inventory year (year i-1), (g)

$ANDOCadded_{Year(i)}$ = ANDOC added during inventory year i, (g)

M = Assumed delay before newly deposited waste begins to undergo anaerobic decomposition (months), default value = 6 months

k = Assumed rate constant for anaerobic decomposition; k = ln2/half-life (years); the half-life being the number of years required for half of the original mass of carbon to degrade (Table 7).

This calculation is performed iteratively for all subsequent years, starting with the landfill opening year and ending with the inventory year of interest.

Table 7: Assumed rate constant values for anaerobic decomposition (k)

Average Rainfall (Inches/Year)	***k value***
<20	*0.02*
20-40	*0.038*
>40	*0.057*

Source: USEPA

(c) Methane Generation

Equation 4; Methane generation in landfills

$$G_{CH4} = F_{CH4} \bullet \left\{ \begin{array}{l} ANDOCstock_{year(i)} \bullet (1 - e^{-k}) \\ + ANDOCadded_{year(i-1)} \bullet [\frac{1}{k} \bullet (e^{-k \bullet [1 - \frac{M}{12}]} - e^{-k}) - \frac{M}{12} \bullet e^{-k}] \\ + ANDOCadded_{year(i)} \bullet [1 - \frac{M}{12} - \frac{1}{k} \bullet (1 - e^{-k \bullet [1 - \frac{M}{12}]})] \end{array} \right\}$$

Where,

G_{CH4}	= CH_4 generated during inventory year i (g)
F_{CH4}	= Fraction of decomposing carbon that is converted into CH_4, default value = 0.5
$ANDOCstock_{Year(i)}$	= Stock of ANDOC present in the landfill at the beginning of inventory year i (g)
$ANDOCadded_{Year(i-1)}$	= ANDOC added during the previous inventory year (year i-1)
$ANDOCadded_{Year(i)}$	= ANDOC added during inventory year i (g)
M	= Assumed delay before newly deposited waste begins to undergo anaerobic decomposition (months), default value = 6 months
k	= Assumed rate constant for anaerobic decomposition; k = ln2/half-life (years); the half-life being the number of years required for half of the original mass of carbon to degrade (Table 7).

(d) Emissions Estimates

Equation 5: CH_4 emissions from landfills

$$E_{CH4} = G_{CH4} \bullet CE_{LFG} \bullet (1 - DE_{LFG}) + G_{CH4} \bullet (1 - CE_{LFG}) \bullet (1 - O_{CH4})$$

Where,

E_{CH4}	= Emissions of CH_4 from landfill (g)
G_{CH4}	= Amount of CH_4 generated by the landfill during the inventory year (g)
CE_{LFG}	= Landfill Gas Collection Efficiency, the fraction of generated landfill gas captured by the collection system (default value = 0.75)
DE_{LFG}	= Landfill Gas Destruction Efficiency, the fraction of CH_4 in the captured landfill gas oxidized to CO_2 (default values = 0.99 for combustion/thermal oxidation, and 0.01 for carbon filtration)
O_{CH4}	= Fraction of uncollected CH_4 that is oxidized to CO_2 in the landfill cover (default value = 0.1)

CIWMB staff provided information about which landfills have gas collection systems and what control method they use, if any. Responses to an ARB survey allowed staff to update a portion of the CIWMB numbers. For years where CIWMB data was lacking on the year of collection system installation (primarily years 1991 - 2003), staff used existing regulatory requirements to help estimate the installation dates. Staff intends to improve the accuracy of collection system installation dates in the future.

Staff assumed that a landfill gained the full benefits of gas collection beginning with the year in which the system was first installed. In the future, as the exact month of installation and start-up operation becomes available, it will be factored in and the collection efficiency for that year may be prorated.

CIWMB staff also provided the type of control landfills are using, including: simple venting to the atmosphere, carbon adsorption, or combustion (flaring, engines, thermal oxidizers, etc.). In the case of combustion, ARB staff assumed that 99 percent of the CH_4 was converted into CO_2 and 1 percent escaped as CH_4. For carbon adsorption, 1 percent of the CH_4 was assumed captured and 99 percent released. For venting 100 percent of the CH_4 was assumed released.

Each site with a gas collection system was assigned a default of 75% percent collection efficiency and a default of 10 percent oxidation for the uncollected landfill gas as it migrates through the landfill cover into the air. Using these default valuesThe defaults of 75 percent for collection efficiency and 10 percent for oxidation fraction has been the object of some debate. Staff recognizes that many values can be found for these factors in the literature and that some site-specific measurements and local estimates do exist. However, given the current lack of rigorous, scientifically-based measurement data, staff chose to use the default values established by USEPA. As better data become available through current and future research, staff will update the collection efficiency and oxidation factors for estimating landfill gas emissions.

(d.i) Use of Site Specific Survey Data

Using the First Order Decay model from the IPCC guidelines, staff estimated the amount of carbon sequestered and the amount of CH_4 emitted by each of the 372 landfills of interest in California.

ARB staff also surveyed landfill operators and some landfills provided site-specific landfill gas collection data for certain years of operations (30 of the 372 landfills submitted site specific survey data). These data were used either to replace or to improve the model's estimates for that landfill.

When staff received landfill survey data for a particular year, it used the survey information in place of the model estimate. However, survey data included only the amount of gas collected, and not the amount generated since landfill operators only know what is measured at the point of collection. To estimate the amount of gas generated, a default collection efficiency of 75 percent was used and the amount of collected gas was divided by 0.75 to obtain an estimate of the generated gas. Then, the estimate of gas generated—based on the amount of gas collected—was used to replace the model estimate for that year.

When an actual value for the CH_4 fraction in landfill gas was reported in the survey, staff used it instead of the general default landfill gas composition assumption of 50 percent CH_4 and 50 percent CO_2. However, because CO_2 specific fractions were not obtained from the site specific survey data (only CH_4 fractions were obtained), it was assumed that whatever was not reported as CH_4 was CO_2. Staff recognizes that N_2 gas and small amounts of O_2 are expected to be present, and therefore not all of the remaining gas (i.e., the fraction that is not CH_4) is CO_2. Nevertheless, the amounts of these other gases were considered to be negligible for the purpose of estimating the CO_2 emissions from landfills. As data improves, this conservative assumption may be revisited.

When landfill survey data was provided for some of the years and not others, staff used the provided years to improve the model estimates for the missing years by interpolating or extrapolating using the model predicted trend for that landfill. For example, if the years 1990-1993 were missing from a set of survey data for a particular landfill, but the year 1994 was available, then the years 1990-1993 were extrapolated from this 1994 data point by following the trend the model showed for that landfill. So if the model indicated that the CH_4 generation in 1993 was 3 percent lower than the 1994 predicted value, the available 1994 value from the survey was multiplied by 97 percent to estimate the 1993 point, and so on. This method of filling missing data preserves a consistent trend that smoothly joins the survey data. The same methodology was used to estimate CO_2 emissions when missing survey data were encountered.

An exception was made to these procedures in the case of survey-reported first years of operation of a collection system. These reported values were not used as a substitute for model estimates, as it was not known if the indicated first year represented a full year of operation. Staff assumed that the second year of reported data was a complete year and used that year as the starting point, ignoring data from the first year. For surveys with collection system data dating back to 1990, staff assumed that the 1990 value represented a full year of operations and always made use of it. Staff made this assumption since data was not available to indicate if 1990 was the first year of operation and no survey data was available for 1989.

(d.ii) Emissions from Landfill Gas Combustion

Emissions of N2O from the combustion of landfill gas are included in the inventory. These emissions are a function of the BTU content of the landfill gas being burned. The amount of landfill gas burned (LFG) is determined from model output for the amount of gas collected and from CIWMB data indicating which landfills burn their captured gas.

Equation 6: N_2O emissions from landfill gas combustion

$$E_{N2O} = LFG \bullet F_{CH4} \bullet HC_{CH4} \bullet EF_{CH4}$$

Where,

E_{N2O}	= N_2O emissions from landfill gas combustion (grams)
LFG	= Landfill gas captured and burned (standard cubic feet)
F_{CH4}	= CH_4 fraction of landfill gas (unitless)
HC_{CH4}	= Heat content of CH_4 (BTU / standard cubic foot)
EF_{CH4}	= N_2O emission factor of CH_4 (grams per BTU)

3. <u>Data Sources</u>

The First order decay model is from the 2006 IPCC guidelines (IPCC, 2006b). Waste characterization data was obtained from studies made by the California Integrated Waste Management Board (CIWMB, 2007d) and by the USEPA (USEPA, 2007b). Degradable Organic Carbon (DOC) content and values for Decomposable Anaerobic Fraction (DANF) were taken from USEPA (USEPA, 2002). DANF data for lumber comes from the California Energy Commission (CEC, 2006). Default values used for DANF and DOC content of waste in place, and CH_4 combustion emission factors were taken from the 2006 IPCC Guidelines (IPCC, 2006b). Default collection capture efficiency and CH_4 oxidation factor values were obtained from the USEPA through personal correspondence (Weitz, 2007). Landfill gas collection, geographic coordinates and control data for California landfills were provided by CIWMB staff through personal communication (Walker, 2007). Average precipitation data for the landfills was extracted from a map published by the NRCS (NRCS, 2007). Methane and nitrous oxide emissions factors are from IPCC Guidelines (IPCC, 2006a).

For a list of yearly activity and parameter values used in the equations, please consult the online documentation annex at:
http://www.arb.ca.gov/cc/inventory/doc/methods_v1/annex_4a_landfills.pdf

4. <u>Future Improvements</u>

More complete, California-specific landfill survey data on landfill gas collection and composition will help improve outputs from the IPCC model. Improved survey data should also establish actual opening dates for landfills and perhaps provide better data on the percent CO_2 content of landfill gas. Better information on the cover types present at landfills and further details on gas collection systems will allow for better collection and oxidation factor estimates. Ongoing research and other studies will be followed closely by staff to improve estimates of landfill gas emissions.

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