LANDFILL OPERATIONS

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1.0 LANDFILLS PROCESS DESCRIPTIONS:

Landfills are emission sources of criteria air pollutants, toxic air pollutants and Greenhouse Gases (GHG). Active sites conduct many activities that produce emissions including, but not limited to: cover material quarrying, soil screening, rock crushing, open cover material storage piles, haul roads, solid waste compaction, cover application, composting, and green waste recycling. Particulate emissions from inactive landfills are usually limited to short term cover maintenance projects. Landfill gases containing methane, carbon dioxide, hydrogen sulfide, and a wide variety of organic compounds are released from the decomposition of waste at all sites. Landfills are generally equipped with gas collection systems which may include vertical and horizontal gas collection wells, headers, fans, and gas disposal equipment, such as flares, or energy recovery systems equipped with internal combustion engines, gas turbines or boilers. Any landfill gas that is not collected through the gas collection system will also be released as fugitive emissions through the surface of the landfill. The quantity of landfill gas released depends primarily on the size, age, and moisture content of each disposal site. Additionally, combustion by-products are emitted from landfills equipped with flares and energy recovery systems. Emission estimation techniques used by the San Diego Air Pollution Control District (the District) are generally based upon methods and emission factors as described below. A brief discussion of each process is provided below.

1.1 COVER MATERIAL QUARRY OPERATIONS

1.1.1 Process Description

All active landfills require substantial amounts of soil and clay for daily cover of the solid waste received. Cover material is almost always excavated from on-site quarries to minimize transport costs and increase disposal space. Landfill quarry operations in San Diego County typically involve minimal equipment (front end loaders, bulldozers, and transport vehicles). Particulate matter released from these activities is most accurately quantified using quarry emission factors from the mineral product facilities.

1.1.2 Emissions Calculations

Emissions from quarry activities are quantified using the District's Emissions Inventory System (EIS)., as described in *Mineral Product Industry – Quarry Activity*[1]

[1] https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Toxics_Program/APCD_quarry1

1.2 SAND / SOIL SCREENING

1.2.1 Process Description

Some landfills use sand / soil screening equipment to increase the amount of available cover material. Screening equipment is usually owned and operated by sub-contractors.

1.2.2 Emissions Calculations

Emissions from sand and soil screening equipment are quantified using EIS, as described in *Aggregate Screening Operations*[2].

1.3 ROCK CRUSHING

1.3.1 Process Description

Some landfills use rock crushing equipment to either convert cobble into cover material or recover usable rock prior to depositing waste materials. Like sand screens, the rock crushing equipment is typically owned and operated by sub-contractors.

1.3.2 Emissions Calculations

Emissions from rock crushing equipment are quantified using EIS, as described in *Aggregate Crushing Operations*[3].

1.4 HAUL ROADS

1.4.1 Process Description

Haul road emissions include all onsite vehicle traffic except for tractors and front-end loaders working the quarry and open storage areas. Typical vehicle traffic at active landfills which must be included in haul road emission estimates are solid waste transport vehicles, green waste transport vehicles, and cover material transport vehicles.

1.4.2 Emissions Calculations

Haul road emissions from both paved and unpaved surfaces are quantified using EIS, as described in *Haul Road Emissions*[4].

1.5 OPEN STORAGE PILES & GREEN WASTE DISPOSAL ACTIVITIES

1.5.1 Process Description

Green waste disposal activities involving tub grinders are common at active landfills. These operations typically consist of segregating the green waste at the collection point and transporting the material to a designated area of the disposal site. Earth moving equipment is used to stockpile the green waste and feed the grinding equipment. The resulting mulch is either used for cover material or transported off-site.

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[2] https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Toxics_Program/APCD_screen1.pdf

[3] https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Toxics_Program/APCD_crusher1.pdf

[4] https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Misc/APCD_Haul_Road.pdf

1.5.2 Emissions Calculations

Particulate emissions from the composting and recycling activities are generated primarily from the earth moving equipment and are similar to those observed at open material storage piles, and therefore are quantified using EIS, as described in *Mineral Products Industry – Open Material Storage Piles*[5]. Note that fuel combustion emissions from diesel fired tub grinders are quantified separately from green waste emissions.

1.6 COVER MATERIAL STORAGE AREAS

1.6.1 Process Description

Open material storage piles and green waste mulching operations commonly exist near the quarry areas or on the top deck of the landfill. These storage areas are sources of particulate emissions caused by material drops, bulldozing, pile formation, wind erosion, and miscellaneous vehicle traffic (i.e. scrappers, front end loaders, etc.). Default concentration values for trace metals in this dust are from mineral product facility test results obtained throughout San Diego County.

1.6.2 Cover Material Application

The compaction of solid waste and application of daily cover material at active landfills results in particulate matter emissions. Active landfills typically receive solid waste at the working face of the disposal site and compact the trash with large bulldozers. Soil cover material is then spread over the compacted solid waste as the working face of the disposal site expands. The activity level and associated particulate emissions from waste transport vehicles, bulldozers, and cover transport trucks at the working face is similar to quarry operations.

1.6.3 Emissions Calculations

Mineral industry quarry factors are used to estimate emissions associated with cover material application. Test results for haul roads at mineral product facilities throughout San Diego County will be used as default concentrations for trace metals in this dust.

Calculation of cover material application emissions is included in the landfill emissions estimates from EIS. The following methods will be used by to estimate these emissions until more accurate information becomes available.

$$\frac{E_a = (U_a * EF * C_i)}{10^6}$$

$$\frac{E_h = (U_d * EF * C_i)}{H * 10^6}$$

Where:

E_a = Annual emissions of each contaminant, (lbs/year)

E_h = Maximum hourly emissions of each contaminant, (lbs/hour)

[5] https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Toxics_Program/APCD_piles1.pdf

U_a = Annual amount of cover material used, (tons/year)
U_d = Maximum daily amount of cover material used, (tons/day)
H = Hours of operation, (hours/day)
EF = Particulate emission factor for cover application operations, (lbs/ton)
= 0.05 lbs TSP/ton = 0.021 lbs PM10/ton
C_i = Concentration of each listed toxic substance in process dust, (ppmw)

2.0 CALCULATION OF LANDFILL GAS FUGITIVE EMISSIONS

2.1 CALCULATION OF UNCONTROLLED, INACTIVE LANDFILL GAS FUGITIVE EMISSIONS

Anaerobic decomposition of inactive landfill waste may generate large amounts of landfill gas composed primarily of methane and carbon dioxide. This gas also contains hydrogen sulfide, a wide variety of trace organic constituents including many chlorinated compounds, as well as toxic air pollutants. The quantity of landfill gas generated is primarily dependent upon the amount, type, age, and moisture content of the disposed waste. While several methods have been developed to estimate inactive landfill gas generation rates, procedures specified in Section 2.4 of AP-42 (9/97) most closely predict actual gas collection rates observed at sites in San Diego County.

Most San Diego County landfills are best quantified as dry sites (landfill gas generation rate constant = 0.02 / yr). Some site-specific circumstances warrant a lower constant (i.e.; Borrego) while other conditions are best quantified using a much higher generation rate (i.e.; NTC, Mission Bay, North Island, etc.).

Default values for landfill gas composition are from AP-42 which was most recently updated in September 1997. All San Diego County landfills have been evaluated as noncodisposal sites. Local SWAT test results support these EPA gas concentration values.

The following methods will be used to estimate fugitive emissions of inactive landfill gas.

$$E_a = \left[L_o * R * (e^{kc} - e^{kt}) - (G_f + G_r) \right] * \frac{(C_i * MW)}{385 * 10^6}$$

$$E_h = \frac{E_a}{365 * 24}$$

Where:

Ea = Annual emissions of each contaminant, (lbs/year)

Eh = Maximum hourly emissions of each contaminant, (lbs/hour)

Lo = Landfill gas generation potential, (ft3 landfill gas/ton of waste)

R = Average annual refuse acceptance rate during active life, (tons waste/yr)

e = Base log, (unitless)

k = Landfill gas generation rate constant, (1/yr)

c = Time since landfill closure (c = 0 for active landfills),(yrs)

t = Time since initial refuse placement, (yrs)

Gf = Gas collection rate for flare systems on site, (ft3/yr)

Ger = Gas collection rate for energy recovery equipment on site, (ft3/yr)

Ci = Concentration of each listed substance in the landfill gas, (ppmv)

MW = Molecular weight of each listed substance in the landfill gas, (lbs/lbmole)

DEFAULT VALUES - LANDFILL GAS GENERATION RATE

Variable	Variable Description	Default Values and Ranges
L0	Landfill gas generation potential	8020 ft3 landfill gas / ton of waste
k	Landfill gas generation rate constant	0.01 / yr (for arid landfills)
k	Landfill gas generation rate constant	0.02 / yr (for dry landfills)
k	Landfill gas generation rate constant	0.03 / yr (for moist landfills)
k	Landfill gas generation rate constant	0.04 / yr (for wet landfills)

Default values for the composition of typical landfill gas are from AP-42. These values closely agree with average results obtained from San Diego county landfills.

Additional information regarding landfill gas generation rates and composition is available in section 2.7 of AP-42. Particulate emission speciation is based on test results from extensive sampling performed at a dozen local mineral processing facilities.

Actual landfill gas collection rates at controlled sites in San Diego County support the overall gas generation rate assumptions and calculations in AP-42. The most recent revision to AP-42 (9/97) has revised the default concentration of NMOC from 1170 ppmv as hexane to 595 ppmv as hexane. Further revisions may occur as addition research is completed.

2.1.1 ASSUMPTIONS / LIMITATIONS:

Site specific test data may be used instead of default values if appropriate. Most of the District default values are based on EPA values which are average results from multiple tests and sites. Since significant variations in test results are common throughout an individual site and over short periods of time, average default values from several sites may be more representative than a single grab sample from the reporting facility.

2.2 CALCULATION OF ACTIVE OR INACTIVE, CONTROLLED LANDFILL GAS FUGITIVE EMISSIONS

Anaerobic decomposition of landfill waste may generate large amounts of landfill gas composed primarily of methane and carbon dioxide. This gas also contains hydrogen sulfide and a wide variety of trace organic constituents including many chlorinated compounds. The quantity of landfill gas generated is primarily dependent upon the amount, type, age, and moisture content of the disposed waste. The amount of landfill gas emitted to the air depends on the Site control measures and post generation gas recovery activities.

While several methods have been developed to estimate landfill gas generation rates, the District has adopted the following methods for quantification

2.3 METHOD: USE OF CARB LANDFILL EMISSIONS TOOL FOR ESTIMATING POTENTIAL LANDFILL GAS FUGITIVE EMISSIONS:

The District has adopted use of California Air Resources Board's (CARB) Landfill Methane Emissions Tool[6] to estimate potential generation rates of landfill gas. The tool was developed by CARB staff to assist municipal solid waste landfill owners and operators in compliance of the Landfill Methane Regulation. The tool is based on a first-order decay model from the 2006 Intergovernmental Panel on Climate Change (IPCC) guidelines and is designed to estimate the fugitive emissions from landfills. It uses the IPCC Second Assessment Report 100-year global warming potential of 21 for methane and includes an estimate of the landfill gas heating value in units of million British thermal units per hour. The model is used by the District primarily for completing engineering evaluations of pre- and post-project emissions associated with permitting activities, where volumes of actual gas collected is not available.

2.4 METHOD: USE OF LANDFILL GAS COLLECTION EFFICIENCY FOR CALCULATING ACTUAL LANDFILL GAS FUGITIVE EMISSIONS

This method is used by the District to calculate actual emissions from landfills equipped with post-generation Gas Disposal Systems, which is the case for all landfills within San Diego County. The method is based on using the amount of landfill gases collected and routed to gas disposal systems to calculate the amount of landfill gas released to the atmosphere through the surface of the landfill.

$$Landfill\ Gas\ Collection\ Efficiency\ (E) = \frac{Amount\ of\ Gas\ Collected\ (G_C)}{Total\ Amount\ of\ Gas\ Generated\ (G_T)}$$

$$Landfill\ Gas\ released\ (Gr) = Total\ Amount\ of\ Gas\ Generated\ (Gt) - Amount\ of\ Gas\ Collected\ (G_C)$$

Based on CARB's *Staff Report: Initial Statement of Reasons for the Proposed Regulation to Reduce Methane Emissions from Municipal Solid Waste Landfills* dated May 2009[7], the District will apply a landfill gas collection efficiency of 85% when calculating fugitive gas in all emission inventories completed for reporting years 2016 and later, if the facility has been

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[6] https://ww2.arb.ca.gov/resources/documents/landfill-methane-emissions-tool

[7] https://ww2.arb.ca.gov/sites/default/files/classic/regact/2009/landfills09/isor.pdf

subject to CARB's regulation to reduce *Methane Emissions from Municipal Solid Waste Landfills*[8]. These regulations were applied in 2016 to all landfills with greater than 450,000 tons of waste in place and received solid waste after January 1, 1977. An 85% landfill gas collection efficiency is used to back calculate the amount of annual and hourly landfill gas released through the surface of the landfill, as follows:

$$G_T = \frac{G_C}{\mathrm{E}}$$

$$G_R = G_T - G_C = \left(\frac{G_C}{\mathrm{E}}\right) - G_C = \left(\frac{G_C}{0.85}\right) - G_C$$

$$G_R = 0.176 * G_C$$

Where:
E: Collection efficiency of landfill gas collection system, 85%

Gc: Landfill gas collected by the collection system and routed to landfill disposal site (SCFH or SCFD or SCFY)

G_T: Total landfill gas generated (SCFH or SCFD or SCFY)

GR: Landfill gas released through the landfill surface (SCFH or SCFD or SCFY)

3.0 CALCULATION OF LANDFILL GAS FLARE EMISSIONS

Most landfills in San Diego County are equipped with gas collection and combustion equipment. Landfill gas fired flares are used on small disposal sites where energy recovery is not economical and on large sites as back-up controls for engines and Turbines Flare emissions consist of NOx, SO_x, CO, PM_{10}, ROG, and TOG as well as trace toxic air contaminants.

Several flares in San Diego County have been source tested to develop emission factors for criteria pollutants and destruction efficiencies for trace toxics. Standard District permitting requirements for stack temperature (1500F to 1800 F) and retention time (minimum 0.3 seconds) have resulted in consistent criteria pollutant emission factors calculated in units of lbs/mmBTU. Flare emissions from combustion of landfill gas are quantified using EIS, as described in calculation method *F04-FLARE,LANDFILL,GAS FIRED,ENCOLSED*[9].

3.1 CALCULATION OF LANDFILL GAS RECOVERY EQUIPMENT EMISSIONS

A number of San Diego County landfills are currently equipped with energy recovery engines that are individually tested on a regular basis. Site specific emission factors exist for NOx and CO. Emissions from combustion of landfill gas are quantified using EIS, as described in calculation method *E11-ENGINE, LANDFILL, GAS FIRED*[10].

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8 https://ww2.arb.ca.gov/sites/default/files/2020-06/landfillfinalfro.pdf
9 https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Misc/EFT/Gas_Combustion/APCD_Flares_Landfill_Gas_Fired_Enclosed.pdf
10 https://www.sdapcd.org/content/dam/sdc/apcd/PDF/Misc/EFT/Gas_Combustion/APCD_Engine_Landfill_Gas_Fired.pdf

3.2 CALCULATION OF TOXIC EMISSIONS FROM COMBUSTION OF LANDFILL GASES

Scientific research has identified volatile organic arsenic and formaldehyde in landfill gas and combustion processes. To accurately characterize the potential emissions from toxic air contaminants emitted and generated from Solid Waste Landfills, the District completed a test program for applicable facilities within San Diego County in order to estimate the potential impact of these contaminants.

3.2.1 Arsenic

Volatile organic arsenic compounds, including Trimethylarsine (TMA), are wellknown products of anaerobic and aerobic microbial processes, commonly found in fuel gas at Solid Waste Landfills. The District tested three active landfills, one closed landfill and three wastewater treatment facilities for the presence of TMA using test methods developed by County Sanitation Districts of Los Angeles County (LACSD), as seen in *Analysis of Volatile Arsenic Compounds in Landfill Gas* [11]. Although arsine was measured during the testing events, it was measured at low levels and the analytical test method had not been validated, therefore the results are estimates and not considered reliable.

LACSD has determined through stack emissions tests of actual devices, that the arsenic content in the exhaust gas from combustion of the landfill gas, was only a fraction of that measured in raw landfill gases. The results of the tests conducted, concluded that on average the measured arsenic in the raw gas using the LACSD method is 52% higher than the amount of arsenic measured in the stack. Therefore, the District has adjusted the arsenic concentrations, and subsequent emission factors, in the raw gas to account for the high biases in the initial testing. Emission factors used to quantify arsenic should be based on the adjusted factors or half the detection limit, whichever is higher. Emission factors of arsenic as listed in Table (1) or those presented by facilities using District approved methods, may be used to quantify emissions from landfill and digester gas.

TABLE 1. ARSENIC EMISSION FACTORS

Facility	Fuel	Collection Date	Total Arsenic[12], ppbv	Adjusted Arsenic EF, lb/MMscf
Miramar at MBC	LFG	5/4/2016	3.2	4.10E-04
Miramar at North City	LFG	6/15/2016	16	2.05E-03
Miramar at North City	LFG	2/28/2017	8.8	1.13E-03
Otay LFG	LFG	6/15/2016	70	8.97E-03
Sycamore Energy	LFG	11/16/2016	96	1.23E-02
Sycamore Energy	LFG	2/28/2017	88	1.13E-02
San Marcos	LFG	1/10/2018	6	7.69E-04

[11] https://www.researchgate.net/publication/272089734_Analysis_of_Volatile_Arsenic_Compounds_in_Landfill_Gas

[12] Total arsenic as Trimethylarsine (TMA)

Encina Wastewater Plant	DG	7/6/2016	2.3	2.95E-04
Point Loma Wastewater Plant	DG	7/13/2016	0.8	1.09E-04
Escondido Wastewater, Hale Avenue, pre control	DG	8/29/2018	1.98	2.54E-04

3.2.2 Formaldehyde

Although not known to be a significant component of landfill gas or digester gas, Formaldehyde is created during the combustion process of these gases and therefore does present a risk. The District's testing program included an assessment of formaldehyde emissions from local equipment by completing source tests at facilities producing landfill or digester gas. Source tests were completed at four landfills and three wastewater treatment facilities using EPA Methods 323 & 316, for a total of 29 tests. Source test concentrations of formaldehyde as listed in Table (2), or those presented by facilities using District approved methods, may be used to quantify emissions from landfill and digester gas.

TABLE 2. FORMALDEHYDE CONCENTRATIONS

Facility	Engine Model	Test Date	CH_2O Measured, ppmv @ 15% O2	CH_2O Measured, lb/hr
Fortistar at Miramar Landfill	Caterpillar G3520	11/4/2014	43.91	2.198
Fortistar at Miramar Landfill	Caterpillar G3520	11/5/2014	44.03	2.189
Point Loma WWTP	Caterpillar G-3612TA	8/14/2014	29.5	1.781
Point Loma WWTP	Caterpillar G-3612TA	8/14/2014	27.5	1.786
Encina WWTP	Caterpillar G-3516	8/8/2014	30.9	0.594
Facility	**Engine Model**	**Test Date**	**CH_2O Measured, ppmv @ 15% O2**	**CH_2O Measured, lb/hr**
Otay Landfill Gas	Caterpillar G3520	6/5/2015	65.76	2.88
Otay Landfill Gas	Caterpillar G3520	6/4/2015	51.26	2.32
Fortistar at Miramar Landfill	Caterpillar G3520	10/27/2015	33.2	1.6
Fortistar at Miramar Landfill	Caterpillar G3520	10/28/2015	38.8	1.9
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/14/2015	26.4	0.64
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/19/2015	27.9	0.68
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/20/2015	28.3	0.67
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/20/2015	25.6	0.64
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/21/2015	31.5	0.7
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/26/2015	33.1	0.8

Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/27/2015	30	0.69
Fortistar at Miramar Landfill	Caterpillar G3516 SITA-IC	5/27/2015	28	0.72
Fortistar and City of SD at North City	Caterpillar G3516 SITA-LE	1/7/2015	33.4	0.796
Fortistar and City of SD at North City	Caterpillar G3516 SITA-LE	1/8/2015	34	0.874
Fortistar and City of SD at North City	Caterpillar G3516 SITA-LE	1/7/2015	32.7	0.754
Fortistar and City of SD at North City	Caterpillar G3516 SITA-LE	1/8/2015	32.3	0.797
Fortistar and City of SD at North City	Caterpillar G3520	5/5/2015	39.2	1.66
Fortistar at San Marcos Landfill	Caterpillar 3516	1/14/2015	42.7	1.043
Fortistar at San Marcos Landfill	Caterpillar 3516	1/13/2015	43.4	1.061
Point Loma WWTP	Caterpillar G-3612TA	7/9/2015	24	1.58
Point Loma WWTP	Caterpillar G-3612TA	7/9/2015	26.9	1.81
Encina WWTP	Caterpillar G-3516	9/8/2015	28	0.6
Encina WWTP	Caterpillar G-3516	9/9/2015	30.2	0.64
San Luis Rey WWTP	Guascor SFGLD 560	2/19/2015	24.5	0.394

4.0 ASSUMPTIONS / LIMITATIONS:

- Site specific test data may be used instead of default values if appropriate. Most of the District default values are based on average results from multiple tests and sites. Since significant variations in test results are common throughout an individual site and over short periods of time, average default values from several sites may be more representative than a single grab sample from the reporting facility.

- Particulate emission factors for quarry operations, solid waste compaction, cover application, and green waste composting / recycling have been estimated using emission factors and methods for similar operations at mineral product industry facilities. These values may be updated when additional information becomes available.

- The composition of landfill particulate emissions is expected to be similar to typical road dust found at mineral processing facilities throughout San Diego County. Only minor variations in trace metal concentrations were detected for approximately a dozen relatively dispersed sites. Site specific sampling may be used instead of default values where necessary.

- The emission estimation technique for paved haul roads from AP-42 is based only on surface silt loading. Variables including truck size, speed, and number of wheels are not specifically considered (Average values appear to be empirically included in the constants). Further refinement of this estimation technique by EPA may be necessary to predict actual landfill's haul road emissions more accurately.

- The Office of Environmental Health Hazard Assessment (OEHHA) has adopted a chronic reference exposure level (REL) for respirable crystalline silica, cristobalite (CAS 14464-46-1) and quartz (CAS 14808-60-7). The REL is based on the PM4 fraction of crystalline silica which is expected to have associated health risks. The District has chosen to implement a health protective value of 7.95% default PM4 to PM10 ratio from published data[13] in order to more accurately estimate the health risks associated with respirable crystalline silica. If available, the District recommends using District approved site-specific data to refine the PM4 to PM10 ratio. The District's current default crystalline silica emission factor is based on local test results, which is 10% of the PM10 default emission factor. The PM4 to PM10 ratio can be accurately applied to the crystalline silica default emission factor since the test results were sized to -10 micron which was used to represent the average composition of PM10. Both crystalline silica as PM10 and respirable crystalline silica as PM4 should be estimated.

- Process data for quarry, open material storage, and haul road emissions at landfills equipped with sand mining equipment and / or rock crushing facilities may be operated by subcontractors. Process data from both the subcontractors and the landfill owners should be carefully reviewed to avoid double counting production rates and/or emissions.

5.0 CALCULATIONS:

Emissions from landfill operations are calculated separately from haul roads, rock processing operations, and combustion equipment. Care should be taken to properly define the "facility" and associated equipment at each landfill to avoid double counting process data and associated emissions.

In many cases, the operation of multiple facilities at a single site are interrelated resulting in difficulties "defining" individual processes. Operations which are commonly interrelated include multiple use quarries, shared open material storage piles, common gas collection systems, and multiple use haul road.

[13] Richards, J. R., Brozell, T., Rea, C. E., Boraston, G., & Hayden, J. (2009). PM_4 Crystalline Silica Emission Factors and Ambient Concentrations at Aggregate-Producing Sources in California. Journal of the Air & Waste Management Association, 59(11), 1287–1295. https://doi.org/10.3155/1047-3289.59.11.128