AIR EMISSIONS GUIDE FOR AIR FORCE TRANSITORY SOURCES

METHODS FOR ESTIMATING EMISSIONS OF AIR POLLUTANTS FOR TRANSITORY SOURCES AT U.S. AIR FORCE INSTALLATIONS

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Solutio
Environmental, Inc.

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Subject: Post-Publication Change to Guide

Guide Users,

After this Guide was written, AFMAN 32-7002, *Environmental Compliance and Pollution Prevention*, was revised and reissued as DAFMAN 32-7002, *Environmental Compliance and Pollution Prevention*. As of 13 June 2025, DAFMAN 32-7002 supersedes AFMAN 32-7002 and references to AFMAN 32-7002 within this Guide may not equate to a corresponding reference in DAFMAN 32-7002. The next version of this Guide will be updated to incorporate the appropriate DAFMAN 32-7002 references.

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D.H. Eric Choe, Solutio Environmental, Inc.

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Based on information and belief formed after reasonable inquiry, the statements and information in this document are true, accurate, and complete.

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ACRONYMS

(Words formed from the initial letters of a name or parts of a series of words.)

AAFES	Army & Air Force Exchange Service
ACAM	Air Conformity Applicability Model
AFCEC	Air Force Civil Engineer Center
AFMAN	Air Force Manual
AGE	Aerospace Ground Equipment
ALAPCO	Association of Local Air Pollutant Control Officials
AMX	Aircraft Maintenance Squadron
APIMS	Air Program Information Management System
ARAR	Applicable or Relevant and Appropriate Requirements
BEE	Bioenvironmental Engineer
BOOS	Burners Out of Service
CAIR	Clean Air Interstate Rule
CALMIM	California Landfill Methane Inventory Model
CARB	California Air Resources Board
CAS	Chemical Abstracts Service
CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
CONUS	Continental United States
DAC	Defense Ammunition Center
DAF	Department of the Air Force
DODIC	Department of Defense Identification Codes
ECOM	External Combustion Engine
EESOH-MIS	Enterprise Environmental, Safety and Occupational Health Management Information System
EIAP	Environmental Impact Analysis Process
EPAct	Energy Policy Act
EPCRA	Emergency Planning and Community Right-to-Know Act
FESOP	Federally Enforceable State Operating Permit
FIRE	Factor Information Retrieval System
HAP	Hazardous Air Pollutant
HAZMART	Hazardous Materials Pharmacy
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilating, and Air Conditioning
ICAO	International Civil Aviation Organization
ICOM	Internal Combustion Engine
LAER	Lowest Achievable Emissions Rate
LandGEM	Landfill Gas Emissions Model
MAJCOM	Major Command

MEM	Mass of Energetic Material
MIDAS	Munitions Items Disposition Action System
NAAQS	National Ambient Air Quality Standards
NAICS	North American Industry Classification System
NASA	National Aeronautics and Space Administration
NEPA	National Environmental Policy Act
NESHAP	National Emission Standards for Hazardous Air Pollutants
NEW	Net Explosive Weight
OCONUS	Outside Continental United States
OTAQ	Office of Transportation and Air Quality
PEMS	Predictive Emission Monitoring System
RCRA	Resource Conservation and Recovery Act
SAR	Second Assessment Report
SAW	Submerged Arc Welding
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SMAW	Shielded Metal Arc Welding
SME	Subject Matter Expert
STAPPA	State and Territorial Air Pollution Program Administrators
VIN	Vehicle Identification Number

BREVITY CODES

(Shortened form of a frequently used group of words, phrase, or sentence consisting of entirely upper-case letters. Each letter is spoken individually)

AB	Afterburner
AEI	Air Emissions Inventory
AERR	Air Emissions Reporting Requirements
AFB	Air Force Base
AFI	Air Force Instruction
AFPMB	Armed Forces Post Management Board
AFRL	Air Force Research Laboratory
APU	Auxiliary Power Unit
BFB	Bubbling Fluidized Bed
BMP	Best Management Practices
BSFC	Brake-Specific Fuel Consumption
CAA	Clean Air Act
CAAA	Clean Air Act Amendments (of 1990)
CE	Civil Engineering
CEMS	Continuous Emission Monitoring System
CEV	Civil Engineering Environmental
CFB	Circulating Fluidized Bed
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CI	Compression Ignition
CNG	Compressed Natural Gas
DLA	Defense Logistics Agency
DoD	Department of Defense
DOE	Department of Energy
EA	Environmental Assessment
EDMS	Emissions and Dispersion Modeling System
EF	Emission Factor
EGBE	Ethylene Glycol Butyl Ether
EIIP	Emissions Inventory Improvement Program
EIP	Emissions Inventory Plan
EIR	Emissions Inventory Report
EIS	Environmental Impact Statement
EOD	Explosive Ordnance Disposal
EPA	Environmental Protection Agency
ERP	Environmental Restoration Program
ESP	Electrostatic Precipitator

ESTCP	Environmental Security Technology Certification Program
FAA	Federal Aviation Administration
FBC	Fluidized Bed Combustor
FCAW	Flux-Cored Arc Welding
FF	Fabric Filter
FFR	Fuel Flow Rates
FFV	Flexible Fuel Vehicles
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
GHG	Greenhouse Gas
GMAW	Gas Metal Arc Welding
GOV	Government Owned Vehicle
GSA	General Services Administration
GSE	Ground Support Equipment
GVW	Gross Vehicle Weight
GWP	Global Warming Potential
HBFC	Hydrobromofluorocarbon
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbon
HCP	Hard Chrome Plating
HEI	High Explosive Incendiary
HEV	Hybrid Electric Vehicles
HHV	High Heat Value
HMA	Hot Mix Asphalt
HVLP	High Volume Low Pressure
HVOF	High Velocity Oxy-Fuel
IC	Internal Combustion
IPCC	Intergovernmental Panel on Climate Change
IPCT	Industrial Process Cooling Towers
IRP	Installation Restoration Program
LDF	Liquid Drift Factors
LEL	Lower Explosive Limit
LFB	Low Flyby
LFP	Low Flight Pattern
LGRVM	Vehicle Management Flight Vehicle Maintenance
LNB	Low NO_X Burner
LPG	Liquefied Petroleum Gas
LTO	Landing and Takeoff
MEK	Methyl Ethyl Ketone
MM	Minutemen Missiles

MPF	Military Personnel Flight
MPO	Metropolitan Planning Office
MSW	Municipal Solid Waste
NACAA	National Association of Clean Air Agencies
NC	Nameplate Capacity
NDI	Non-Destructive Inspection
NEI	National Emission Inventory
NMHC	Non-Methane Hydrocarbons
NMOC	Non-Methane Organic Compounds
NMTOC	Non-Methane Total Organic Compounds
NSCR	Non-Selective Catalytic Reduction
NSPS	New Source Performance Standards
NSR	New Source Review
OBOD	Open Burning/Open Detonation
OBODM	Open Burning/Open Detonation Model
OCA	Off-Site Consequences Analysis
ODC	Ozone Depleting Chemicals
ODP	Ozone Depletion Potential
ODS	Ozone Depleting Substances
OIAI	Once In Always In
OLVIMS	On-line Vehicle Interactive Management System
P2	Pollution Prevention
PAH	Polycyclic Aromatic Hydrocarbon
PBT	Persistent Bioaccumulative and Toxic
PM	Particulate Matter – Aerodynamic diameter unspecified
PM_{10}	Particulate Matter – Aerodynamic diameter < 10 micrometers
$PM_{2.5}$	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
POL	Petroleum, Oil, and Lubricant
POTW	Publicly Owned Treatment Works
POV	Privately Owned Vehicles
PSD	Prevention of Significant Deterioration
PTE	Potential to Emit
RMP	Risk Management Plan
RVP	Reid Vapor Pressure
SCC	Source Classification Code
SDS	Safety Data Sheets
SCR	Selective Catalytic Reduction
SF	Spillage Factor
SI	Spark Ignition
SNCR	Selective Non-Catalytic Reduction

TCLP	Toxicity Characteristic Leaching Procedure
TDS	Total Dissolved Solids
TGO	Touch-and-Go
THC	Total Hydrocarbons
TLG	Total Landfill Gas
TNMOC	Total Non-Methane Organic Compounds
TO	Technical Order
TOC	Total Organic Compounds
TOG	Total Organic Gas
TRI	Toxic Release Inventory
TSD	Treatment, Storage, & Disposal
TSP	Total Suspended Particulate
ULSD	Ultra-Low Sulfur Diesel
US	United States
USDA	United States Department of Agriculture
UST	Underground Storage Tanks
UV	Ultraviolet
VKT	Vehicle Kilometers Traveled
VMIF	Vehicle Maintenance Index File
VMT	Vehicle Miles Traveled
VOC	Volatile Organic Compound

ABBREVIATIONS

(Shortened form of a word or phrase)

µg	Microgram(s)
A-hr	Ampere-hours
A/ft^2	Ampere per square foot
Btu	British Thermal Unit
°C	Degrees Celsius
CH_4	Methane
CO	Carbon Monoxide
CO_2	Carbon Dioxide
Co	Cobalt
Cr	Chromium
Cr^{+6}	Hexavalent Chromium
Cr_2O_3	Chromium Oxide
EtO	Ethylene Oxide
°F	Degrees Fahrenheit
ft	Foot (feet)
g	Grams
g/L	Grams per Liter
gal	Gallon(s)
HCl	Hydrochloric Acid
hp	Horsepower
hr	Hour(s)
kg	Kilogram
kW	Kilowatt(s)
L	Liter
lb	Pound(s)
Mg	Megagram(s) [i.e., metric ton]
mg	Milligram(s)
MMBtu	Million British Thermal Units
Mn	Manganese
NH_3	Ammonia
Ni	Nickel
N_2O	Nitrous Oxide
NO_2	Nitrogen Dioxide
NO_X	Nitrogen Oxides
O_3	Ozone
Pb	Lead
PERC	Perchloroethylene

PFC	Perfluorocarbon
ppm	Parts per Million
ppmv	Parts per Million by Volume
ppmw	Parts per Million by Weight
psi	Pounds per Square Inch
psia	Pounds per Square Inch Absolute
°R	Degrees Rankine
scf	Standard Cubic Feet
SF_6	Sulfur Hexafluoride
SO_2	Sulfur Dioxide
SO_X	Sulfur Oxides
TNT	Trinitrotoluene
tpy	Tons per Year
yr	Year (s)

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1 INTRODUCTION

1.1 Background and Purpose

Congress passed the Clean Air Act in 1970, and amended it in 1977 and 1990 to better control hazardous air emissions and reduce the amount of harmful pollutants expelled into the air. The US EPA is responsible for protecting the public and the environment by establishing standards such as the CAA aimed at reducing pollutant emissions. Additionally, the EPA also established the National Ambient Air Quality Standards (NAAQS) that require facility managers to always be aware of their facility's compliance status with Federal air quality regulations.

For an installation, such as an Air Force base, air pollutant emissions may be determined by conducting an Air Emissions Inventory (AEI). An AEI is a compilation of the air pollutant emissions in a given area over a period of time, typically one year, and are used to help determine significant sources of air pollutants, establish emission trends over time, and target regulatory actions. **Note that transitory emission sources have often been erroneously included in stationary and mobile AEIs. However, transitory sources should not normally be included in a stationary or mobile AEI unless the source becomes fixed and/or routinely operated (i.e., year-round emitter).**

This document covers transitory sources and their emissions that may be located on an Air Force Installation. Any questions concerning this document, calculation methodologies for sources not provided here, or requests for additional information pertaining to Air Force AEIs should be directed to the Air Quality Subject Matter Expert, Air Force Civil Engineer Center (AFCEC), Compliance Technical Support Branch, 2261 Hughes Ave., Ste 155 JBSA Lackland, Texas 78236-9853

1.2 Transitory Sources

Emission sources may be regarded as mobile, stationary, or transitory. Every emissions source should be correctly categorized because of the potential ramifications of determining if a facility is a **"major source"** (defined in a subsequent section –1.4.1 CAA Titles) of air pollutants. This Guide is concerned only with emissions from transitory sources likely to be found at a Department of the Air Force (DAF) base. For emissions calculation methodologies pertaining to mobile or stationary sources, refer to the latest versions of the *Air Emissions Guide for Air Force Mobile Sources* or *Air Emissions Guide for Air Force Stationary Sources*.

Transitory sources are <u>non-routine</u> and/or <u>seasonal sources</u> (may be stationary, mobile, or neither) that are short-term in nature. Historically, transitory sources have been erroneously included as stationary or mobile sources in AEIs. Transitory source emissions should generally only be accounted for in evaluating potential air quality impacts of proposed actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), National Environmental Policy Act (NEPA), and General Conformity.

This Guide addresses transitory emissions sources typically found on DAF installations. Sources of emissions may be further subdivided as:

- **Point Sources** – not naturally occurring, discrete sources of emissions which emit through a stack, chimney, vent, or other functionally equivalent opening. Examples include stationary engines, boilers, and paint booths.
- **Fugitive Sources** – not naturally occurring sources of emissions which could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening. Examples include open burns, firefighter training, and pesticide application.
- **Biogenic Sources** – naturally occurring sources of emissions. Examples include emissions from soil and vegetation, lightning, and volcanic emissions.

Since only point and fugitive source emissions are applicable to DAF installations because of their direct bearing on the determination of major source status, biogenic sources are not addressed within this Guide.

1.2.1 Non-routine Sources

Non-routine sources are irregular, non-continuous, and/or infrequent sources of emissions. Generally, air quality concerns for non-routine sources are addressed as Applicable or Relevant and Appropriate Requirements (ARAR) under other environmental laws (e.g., CERCLA for all sources associated with site restoration/remediation). Examples of non-routine sources typically associated with an Air Force installation include bulk storage tank cleaning, fuel spills, prescribed burning, wildfires, and all sources associated with site restoration/remediation.

Non-routine sources should only be considered stationary sources if they are fixed at one location for one (1) year or greater, operational/occurring on a repetitive basis, and declared stationary by an applicable regulatory authority.

1.2.2 Seasonal Sources

Seasonal sources are portable or semi-portable sources that are set up at a site for a specific temporary purpose before being re-located and used at another site. Seasonal sources typically associated with an Air Force Installation include seasonal equipment, hot mix asphalt plants, and all sources associated with construction.

Seasonal mobile sources are those that are non-stationary and include both "on-road" and "off-road" engines and equipment. Data for mobile sources are based on engine size, vehicle weight, equipment type, and/or horsepower. On-road vehicles include automobiles used for the transport of passengers or freight. Nonroad sources include a multitude of equipment used for construction, agriculture, recreation, and many other similar purposes.

Seasonal sources should only be considered stationary sources if they are fixed at one location on a permanent basis for at least two (2) years and operated at that single location for three (3) or more months each year.

1.3 Pollutants

The pollutants addressed in this Guide include criteria pollutants, Hazardous Air Pollutants (HAPs), and Greenhouse Gases (GHGs). A description of each pollutant class is presented below.

1.3.1 Criteria Pollutants

In 1971, the EPA established NAAQS for six pollutants, collectively called criteria pollutants. The EPA designates these six pollutants as "criteria" air pollutants because it regulates them by developing human health-based and/or environmentally based criteria for setting permissible levels. These criteria pollutants are:

Particle Pollution – often referred to as Particulate Matter (PM):

- PM includes the very-fine dust, soot, smoke, and droplets formed from chemical reactions and incomplete burning of fuels.
- The fine particles of PM can get deep into the lungs, causing increased respiratory illnesses and tens of thousands of deaths each year.
- PM is defined as any particle with an equivalent diameter of less than or equal to 10 microns (**PM_{10}**) and is further subdivided to include a separate standard for particles with an equivalent aerodynamic diameter of less than or equal to 2.5 microns (**$PM_{2.5}$**).

Ground-Level Ozone (O3):

- O_3 is a primary component of smog that causes human health problems and damage to forests and agricultural crops.
- Repeated exposure to O_3 can make people more susceptible to respiratory infections and lung inflammation.
- Though there is a NAAQS, **O_3 is not emitted directly into the air.**

- Two types of compounds that are the main ingredients (precursors) in forming ground-level O_3 in the presence of ultraviolet (UV) light include:
    - **Volatile Organic Compounds (VOCs):** Defined as "any compound of carbon, excluding carbon monoxide (CO), carbon dioxide (CO_2), carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions" (40 CFR 51.100). Note that 40 CFR 51.100 also exempts compounds based on their negligible photochemical reactivity. Examples of these exempt compounds include methane, ethane, acetone, et al. Common sources of VOCs include gas and diesel-fueled automobiles, fuel storage containers, and solvents used in paints and degreasers.
    - **Nitrogen oxides (NO_X):** Provides the reddish-brown tint in smog. These are produced from the burning of gasoline, coal, or oil.

Carbon Monoxide (CO):

- CO is produced when fossil fuel burns incompletely because of insufficient oxygen (O_2).
- Wood, coal, and charcoal fires and gasoline engines always produce CO.
- In the United States, particularly in urban areas, most CO air emissions are from mobile sources.
- CO can cause harmful health effects by reducing O_2 delivery to the body's organs (like the heart and brain) and tissues.

Sulfur Oxides (SOX):

- Sulfur Oxides are a group of molecules made of sulfur and oxygen atoms, such as Sulfur Dioxide (SO_2), and Sulfur Trioxide (SO_3).
- Since SO_2 is the most common form of the sulfur oxides, the EPA uses it as an indicator for the larger group of SO_X.
- SO_2 in the ambient air is just one of several sulfur oxides that contribute to air quality issues.
- SO_X emissions are produced from fossil fuel combustion at power plants (73 percent) and other industrial facilities (20 percent)
- SO_X is linked to several adverse effects on the respiratory system.

Nitrogen Oxides (NO_X):

- Nitric Oxide (NO), Nitrogen Dioxide (NO_2), and nitrate radicals (NO_3) are collectively called Nitrogen Oxides (NO_X)
- NO_2 is a subgroup of nitrogen oxides and is the most environmentally concerning component. It also acts as an indicator for the presence of the larger group of NO_X.
- NO_X forms quickly from vehicle, power plant, and off-road equipment emissions.
- NO_X contributes to the formation of ground-level O_3 and fine particle pollution.
- NO_X causes airway inflammation and can increase breathing problems for people with compromised respiratory systems (e.g., asthma).

Lead (Pb):

- Pb is a metal found naturally in the environment as well as in manufactured products.
- Prior to 1980, the major sources of Pb were on-road vehicles. As a result, the EPA removed Pb from motor vehicle gasoline, resulting in a 95% decline in Pb emissions between 1980 and 1999.
- Today, the major sources of Pb are ore and metals processing (e.g., lead smelters).
- Depending on the level of exposure, Pb can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems, and the cardiovascular system.

Note that lead is both a criteria pollutant and a HAP, and an Emission Factor (EF) is commonly provided in both the criteria pollutant and speciated HAPs tables within this Guide. Care should be taken to avoid the overestimation of this pollutant caused by duplicating emissions estimates using the same Pb EFs from the criteria pollutant and speciated HAPs tables provided. For a current list of the NAAQS for criteria pollutants, refer to 40 CFR 50.

Also, note that O_3 is not directly emitted into the air, but is created through photochemical reactions involving NO_X and VOCs, and PM may be the result of the release of primary pollutants or the formation of secondary pollutants. Therefore, this Guide provides EFs for a list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of "criteria pollutants" for emissions inventory purposes are reported as those shown below:

- CO
- NO_X
- PM_{10}
- $PM_{2.5}$
- SO_X

- VOCs
- Pb

1.3.2 Hazardous Air Pollutants (HAPs)

According to the EPA, “Toxic air pollutants, also known as HAPs, are those pollutants that are known or suspected to cause cancer or other serious health effects, such as reproductive effects or birth defects, or adverse environmental effects.” Section 112(b) of the CAA provided an initial list of HAPs including specific chemical compounds and compound classes. The EPA is charged with the periodic review and revision of this list and has established procedures for both “listing” and “delisting” compounds. A total of 189 compounds were on the original HAP list, though four compounds have since been removed: Hydrogen Sulfide in December 1991, Caprolactam in June 1996 (61FR30816), Ethylene Glycol Monobutyl Ether (EGBE) removed from the “glycol ethers” category in November 2004 (69FR69320), and Methyl Ethyl Ketone (MEK) in December 2005 (70FR75047). The most current list of HAPs available at the time of this writing is provided at the end of this Guide in Appendix A – EPA HAP List.

1.3.3 Greenhouse Gases (GHGs)

With global impacts of GHGs (climate change) becoming one of the most important issues of the 21st century, more scrutiny has been placed on the emission of GHGs. Some GHGs, such as CO_2, are emitted to the atmosphere through both naturally occurring processes as well as human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities. The principal GHGs emitted to the atmosphere through human actions are CO_2, methane (CH_4), nitrous oxide (N_2O), and fluorinated gases.

CO_2 is the primary GHG emitted through human activity, accounting for 82 percent of all GHG emissions from human actions in the United States. CO_2 enters the atmosphere primarily through the burning of fossil fuels and industrial processes. CO_2 is also removed from the atmosphere (or “sequestered”) when it is absorbed by plants and the ocean as part of the global carbon cycle. CH_4 is emitted during the production and transport of coal, natural gas, and oil. CH_4 emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. N_2O is emitted during agricultural and industrial processes, as well as during combustion of fossil fuels and solid waste.

GHGs are assigned a Global Warming Potential (GWP), which is a measure of how much heat the gas traps in the atmosphere calculated over a specific time interval, typically 100 years. The higher the GWP, the greater the potential for the gas to trap heat, and the more harmful the gas is regarded. CO_2 is used as the baseline gas and assigned a GWP of 1. GHG emissions are converted into equivalent CO_2 (CO_2e) by taking the product of the emissions of each GHG and its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several GHGs. The

GWP values given throughout this Guide are subject to change in the upcoming years due to new data becoming available but are considered current as of June 2021. The total GHG emissions are calculated by summing all emissions from each gas and is generally derived from the following equation:

$$\boldsymbol{E(CO_2e) = \sum_{i=1}^{n}[E(GHG)_i \times GWP(GHG)_i]}$$

Equation 1-1

Where,

E(CO_2e) = Greenhouse gas emissions expressed as CO_2 equivalent (CO_2e)
E(GHG)$_i$ = Emissions of individual GHG species i
GWP(GHG)$_i$ = Global warming potential for GHG species, i
i = GHG species, most commonly CO_2, CH_4, and N_2O

1.4 Applicable Air Quality Related Regulations

1.4.1 CAA Titles

Title I of the CAA requires each state to develop a State Implementation Plan (SIP), which identifies sources of air pollution and the plans for reducing emissions to meet the Federal air quality standards. Under Title I of the CAA, the EPA is also tasked with establishing and enforcing New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAP), which are aimed at reducing emissions from new stationary sources and controlling emissions of HAPs, respectively.

Since the development of the CAA in 1970, changes have been made to better improve the guidelines on hazardous emissions. In 1990, an amendment was made for the CAA known as Clean Air Act Amendment of 1990 (CAAA-90). Title III of CAAA-90 further directed the EPA to develop a list of sources that emit HAPs and establish regulations for each source category. Major sources and area sources for HAPs are required to abide by the "Maximum Achievable Control Technology" (MACT) standards issued by the EPA that has a prescribed schedule. Under Title V of the CAAA-90, those stationary sources that are considered a "major source" must obtain a Title V operating permit. A major source under Title V includes any stationary source or group of stationary sources within contiguous or adjacent property and under common control that emit or has the potential to emit:

- 10 tpy or more of any HAP **or** 25 tpy or more of any combination of HAPs
- 100 tpy or more of any air pollutant subject to regulation. For some of the criteria pollutants, lower thresholds exist for certain nonattainment areas including:
    - 50 tpy of VOC and NO_X emissions in "serious" O_3 nonattainment areas and in O_3 transport regions.

- 25 tpy of VOC and NO_X emissions in "severe" O_3 nonattainment areas.
- 10 tpy of VOC and NO_X emissions in "extreme" O_3 nonattainment areas.
- 50 tpy of CO emissions in "serious" CO nonattainment areas.
- 70 tpy of PM_{10} emissions in "serious" PM_{10} nonattainment areas.

1.4.1.1 New Source Review (NSR)

The New Source Review (NSR) permitting program was established as part of the 1977 CAA amendments to ensure that air quality is not significantly degraded because of new construction or modifications at existing facilities. The NSR permits establish how a source is to be operated, its emissions limits, and what construction is allowed for the modification of that source. NSR requires stationary sources of air pollution to obtain permits prior to construction. There are three types of NSR permitting requirements. Prevention of Significant Deterioration (PSD) permits, Nonattainment NSR permits, and minor source permits.

PSD permits are required for new major sources or major modifications at existing sources in attainment areas. The PSD program requires that any new construction or modification must use the Best Available Control Technology (BACT) and perform air quality and environmental impact analysis. There are 28 source categories given in 40 CFR 51.166 which, if they emit 100 tpy, **including fugitive emissions,** are regarded as PSD major sources. Sources that do not fall into one of the 28 categories are regarded as PSD major sources if they emit 250 tpy, **excluding fugitive emissions.** Generally, there are only three sources that fall into one of these categories that may potentially be found on a DAF installation. These sources are fossil fuel boilers (or combination thereof) totaling more than 250 Million British Thermal Units per hour (MMBtu/hr) heat input; petroleum storage units with a capacity exceeding 300,000 barrels (9.45 million gallons); and any other stationary source category which, as of August 7, 1980, is being regulated under section 111 or 112 of the Act. The local air pollution control agency may provide additional information regarding the PSD permit application process, required for PSD major sources, as well as the typical length of time it takes before a permit is issued.

Nonattainment NSR permits are required for new major sources or major modifications at existing sources located in nonattainment areas. All nonattainment NSR programs require the installation of the Lowest Achievable Emission Rate (LAER). LAER is determined either by taking the most stringent emission limitation contained in a SIP for the category source or the most stringent emission limit achieved in practice by such class or category of source, whichever is more constraining. Additionally, since the construction is to take place in a nonattainment area, part of the nonattainment NSR program requires some form of emission offsets. Emission offsets are reductions in emissions from existing sources near the proposed construction that are greater than the emissions increase from the new source. This will prevent the net air quality emissions from increasing above the permitted threshold.

Minor NSR permits are required for new construction that does not require PSD or nonattainment NSR permits. These permits contain requirements limiting the emissions to avoid PSD and nonattainment NSR, and to prevent the new construction from violating the control strategy in a nonattainment area.

1.4.1.2 General Conformity

Section 176(c) of the CAA prohibits Federal activities from taking various actions in nonattainment or maintenance areas unless they first demonstrate conformance with their respective SIP. "A Federal Agency must make a determination that a federal action conforms to the applicable implementation plan in accordance with the requirements of this subpart before the action is taken" (40 CFR 93.150(b)). A conformity review is a multi-step process used to determine and document whether a proposed action meets the conformity rule. There are two main components to this process: an **applicability analysis,** which establishes if a full-scale conformity determination is required and, if it is, a **conformity determination**, which assesses whether the action conforms to the SIP. The general conformity program requires all Federal actions in nonattainment and maintenance areas to comply with the appropriate SIP. An emissions inventory is usually required as part of the conformity determination to identify/quantify air emissions from the proposed Federal actions.

Note that the conformity process is separate from the NEPA analysis process, though the two may be integrated. There are certain requirements for NEPA that are not required under conformity. For example, NEPA requires the development of reasonable alternative actions, whereas conformity only requires analysis of the proposed action.

1.4.2 National Environmental Policy Act (NEPA)

NEPA requires Federal agencies to evaluate the environmental impacts associated with proposed actions that they either fund, support, permit, or implement. There are three levels of analysis:

- **Categorical Exclusion Determination** - A Categorical Exclusion Determination is a proposed action that may be categorically excluded from a detailed environmental analysis if the action meets certain criteria that a previous agency has previously determined to have no significant environmental impact.
- **Environmental Assessment (EA)** – An Environmental Assessment is a proposed action not categorically excluded and must be evaluated to determine if its undertaking would significantly affect the environment. If there is no significant affect, the agency issues a Finding of No Significant Impact (FONSI). If the EA concludes the action results in a significant environmental impact, an Environmental Impact Statement must be prepared.

- **Environmental Impact Statement (EIS)** – An EIS is a detailed evaluation of the proposed action and its alternatives. A draft EIS is filed with the EPA and the EPA publishes a “Notice of Availability” in the Federal Register. Publication of the “Notice of Availability” begins a 45-day public comment period and mandatory 30-day waiting period before the agency can decide on the proposed action.

1.4.3 Environmental Impact Analysis Process (EIAP)

The Environmental Impact Analysis Process (EIAP) is the Air Force’s tool for implementing procedures for environmental impact analysis within the United States and abroad. Within the United States, EIAP maintains compliance with NEPA and the Council on Environmental Quality (CEQ) Regulations for Implementing the Procedural Provisions of the NEPA (40 CFR Parts 1500 through 1508). DAF environmental impact analyses of actions outside the United States are to be in accordance with Executive Order (EO) 12114, Environmental Effects Abroad of Major Federal Actions and 32 CFR 187, Environmental Effects Abroad of Major Department of Defense Actions.

1.5 Authoritative Algorithms and Emission Factors (EFs)

An EF is a representative value that attempts to relate the quantity of a pollutant released with the activity associated with the release of that pollutant. These factors are usually expressed as the weight of pollutant released per a unit weight, volume, distance, or duration of the pollutant emitting activity. In most cases, these factors are simply averages of all available data of acceptable quality and are generally assumed to be representative of long-term averages for all facilities in the source category.

This Guide is the DAF single authoritative compilation of algorithms and EFs for transitory sources. No other algorithms or EFs shall be used unless mandated by a legally enforceable regulatory requirement (e.g., permit stipulation) or approved by AFCEC/CZTQ on a case-by-case basis. Algorithms and EFs used by the DAF are generally from the *Compilation of Air Pollutant Emission Factors* (AP-42) and WebFIRE (EPA’s online EF database). However, data in AP-42 is often obsolete due to equipment updates that occur more frequently than EF research and WebFIRE is known to contain errors and conflicting data. Additionally, EFs for Air Force-unique circumstances and sources have been developed by the DAF and are only available in this, the Stationary, and Mobile Source Guides. Therefore, the only algorithms and EFs authorized for use in estimating DAF air emissions are those maintained within this and other official DAF source guides, unless a specific temporary exemption is approved by AFCEC/CZTQ.

APIMS is the Air Force-approved information system for air quality, which provides a standardized, integrated tool and methodology to track, manage, and report all data related to the Air Quality Program. In accordance with AFMAN 32-7002, APIMS is mandated for use in air quality permit management, air emission inventory, vehicle inspection & maintenance certification, and air emissions reporting. The Installation/Base Civil Engineer – Environmental Element must ensure the air quality compliance and resource management data are accurately maintained in APIMS in a timely manner.

APIMS is mandated by AFMAN 32-7002 for estimating DAF AEI. This Guide is the single authoritative compilation of algorithms and EFs, however, APIMS is periodically updated so that the EFs and algorithms agree with the current source guide. All algorithms and EFs within APIMS must be from within this and other official DAF source guides (unless specifically approved by AFCEC/CZTQ). Upon discovery of any unauthorized algorithms and/or EFs within APIMS, contact the APIMS Help Desk for removal or pursuing temporary authorization from AFCEC/CZTQ.

1.6 Emissions Inventory Methodologies

Transitory sources have similar characteristics to stationary sources and share the same methodology for calculating emissions. The purpose of this Guide is to provide a uniform approach to calculating AEIs. This effort is due to the common errors found in emissions inventories such as missing or duplicate facilities, missing operating or technical data, data entry and transcription errors, incorrect Safety Data Sheets (SDS), and calculation errors. Care should be made to reduce errors and improve the quality of the data. When conducting an AEI, several methods can be used to quantify air pollutants from emission sources. The methods listed below start at the most expensive and most reliable method for estimating emissions and progresses to the least expensive, least reliable method:

- Emissions monitoring/sampling (e.g., continuous emissions monitoring or stack sampling)
- Mass balances
- Source category emissions model
- State/industry factors
- Emission factors
- Engineering estimates

Data from source-specific emission tests or continuous emission monitors are usually preferred for estimating a source’s emissions, because that data provides the best representation of the tested source’s emissions. However, test data from individual sources are not always available and, even when presented, may not reflect the variability of actual emissions over time. Thus, EFs and/or material balance calculations are frequently the best or only method available for estimating emissions, despite their limitations. In all cases, managers must analyze the tradeoffs between the cost and quality of the emissions estimates. Where risks of either adverse environmental effects or adverse regulatory outcomes are high, more sophisticated, and costlier emission determination methods may be necessary. Though most emission calculation methods presented in this Guide use either EF estimates, material balance calculations, or available modeling software, they are not meant to suggest these are the only alternatives available.

Many EFs found in this Guide were taken directly from AP-42 where they were assigned a data quality rating from "A" through "E", with "A" being the best quality. The factor's rating is a general indication of the reliability of that factor based on the quality of the test and how well the factor represents the emission source. Additional or alternative EFs may be available from other sources, most notably the California Air Resource Board (CARB). If an EF for a specific pollutant or process is not available, that does not mean the EPA believes the source should not be inventoried, but that there is insufficient data to provide guidance.

AFMAN 32-7002 states that AEIs should be prepared and updated via APIMS. The default EFs in APIMS are those found in this Guide. However, alternative EFs, such as those requested by state and local air regulators, may be used if the alternative EF is submitted and approved by AFCEC/CZTQ. The general equation for emissions estimation using an EF is:

$$\boldsymbol{E = A \times EF \times \left(1 - \frac{ER}{100}\right)}$$

Equation 1-2

Where,

E = Total Emissions Released
A = Activity Rate
EF = Emission Factor
ER = Overall Emission Reduction Efficiency (%)

The overall emission reduction efficiency is the product of the control device destruction or removal efficiency and the capture efficiency of the control system. When estimating emissions for an extended period, an average efficiency is used to account for routine operations. In some cases, a material balance approach may provide a better estimate of emissions than emission tests. In general, material balances are appropriate for use in situations where a high percentage of material is lost to the atmosphere. All the materials going into and coming out of the process must be considered to allow an emission estimation to be credible.

1.7 Guide Organization

This Guide is organized into chapters that are specifically related to facilities or processes typically found at Air Force installations. Chapter topics may or may not correspond directly to source types identified in EPA, state, or local guidance documents. The intent is to consider sources usually associated with a facility/activity/process. This Guide specifically addresses transitory sources of air emissions. Guidance for addressing mobile or stationary sources of air pollutants may be found in the latest versions of the *Air Emissions Guide for Air Force Mobile Sources* or *Air Emissions Guide for Air Force Stationary Sources*, respectively.

1.8 References

40 CFR 50, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Subchapter C-Air Programs, Part 50-National Primary and Secondary Ambient Air Quality Standards,” U.S. Environmental Protection Agency

40 CFR 51, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Subchapter C-Air Programs, Part 51-Requirements for Preparation, Adoption, an Submittal of Implementation Plans,” U.S. Environmental Protection Agency

40 CFR 93, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Subchapter C-Air Programs, Part 93-Determining Conformity of Federal Actions to State or Federal Implementation Plans,” U.S. Environmental Protection Agency

40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting,” U.S. Environmental Protection Agency

40 CFR Chapter V, “Title 40-Protection of the Environment, Chapter V-Council on Environmental Quality,” U.S. Environmental Protection Agency

2 BULK STORAGE TANK CLEANING (TCRL)

- *Fugitive* Source

2.1 Introduction

Storage tanks located on Air Force installations are used for storing materials, which commonly include fuels such as JP-8, Jet A, MOGAS, and diesel, or even asphalt solvents. These compounds are composed of VOCs and HAPs, which are released into the atmosphere as the liquid evaporates. The storage tanks may contain anywhere from a few hundred to over a million gallons and may be located above ground or underground. According to the EPA, an underground storage tank (UST) is defined as a tank and any underground piping system that has 10% or more of its combined volume underground. Liquid storage tanks that have more than 90% of their volume above the ground surface are classified as above ground storage tanks (AST). Various types of tanks can be used for storage, but the most common types found on an AF installation are tanks with a roof that is either a self-supporting fixed roof or an external floating roof type. Other tank types include internal floating roof and column-supported fixed roof tanks.

All storage tanks are occasionally emptied and cleaned for activities such as service changes, maintenance, and inspections. Cleaning bulk storage tanks is considered a non-routine source because it is infrequently conducted. Emissions result from vapor displacement, the evaporation of any clinging liquid within the tank, and from the evaporation of VOCs contained within the remaining sludge. Most wet sludge is composed of about 80% to 90% liquid by weight (USEPA 2012). For emissions calculations, the sludge may be conservatively assumed to be 80% liquid by weight, with the remaining 20% composed of VOCs that are entirely emitted to the atmosphere. **Bulk storage tank cleaning operations result in fugitive emissions of VOCs and HAPs.** A graphic representation of emissions from bulk storage tank cleaning operations is given in Figure 2-1.

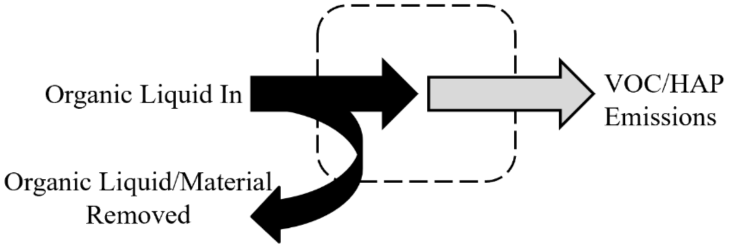

Figure 2-1. Simplified Bulk Storage Tank Cleaning Control Volume

There are several types of roof designs for storage tanks that determine the amount of emissions released from tank use, though have no effect on the amount of emissions released during tank cleaning. For more data on storage tanks and their emissions, refer to the "Storage

Tanks" chapter of the latest version of the *Air Emissions Guide for Air Force Stationary Sources*.

The process of cleaning a storage tank may involve the following steps:

- The liquid in the storage tank may first be tested for contamination.
- Liquid from the tank is removed and placed in a vacuum truck.
- Vapor space is de-gassed.
- Remaining liquid/sludge is removed. This may involve the addition of distillates to flush the tank.
- If needed, the tank may be ventilated to allow for safe entry for manual inspection.
- Liquid is filtered out of the vacuum truck and back into the tank.
- The filtered liquid is re-tested and chemical corrections are made, as needed.

Emissions from the cleaning of storage tanks are the result of tank degassing and cleaning, which includes sludge handling and degreasing. The process of emptying and refilling a tank is known as a tank turnover.

2.2 NESHAP Applicability

There are several NESHAPs applicable to storage tanks provided in 40 CFR 63 Subparts OO, WW, EEEE, and CCCCCC. These standards detail the requirements for the operation of storage tanks and any control devices that may be required during their use including applicability and compliance with work practice standards. Refer to the applicable subpart for detailed information regarding the frequency and work practice standards for degassing, maintenance, inspection, and cleaning of storage tanks.

2.3 Control Techniques

There are several control techniques available for the capture and breakdown of VOCs and HAPs from storage tanks prior to their release into the atmosphere. During the process of degassing, the vapor from the storage tanks may flow through a carbon adsorption system, liquid scrubber, thermal oxidizer, or refrigerated vapor recovery system. In a carbon adsorption system, VOCs and HAPs are removed as the highly porous carbon works as a filter in the gas stream. Liquid scrubbers work by dissolving pollutants in liquid droplets and removing them from the inlet gas stream. Thermal oxidizers work by introducing the inlet stream to a burner where, after an extended residence time, the VOCs within the stream are thermally destroyed. Refrigerated vapor recovery systems pass the VOC saturated inlet stream through a series of condensers, converting the contaminants into liquid. The liquid is sent to a holding tank awaiting disposal. This type of control technique can recover up to 99% of the VOCs from the inlet gas stream.

2.4 Emissions Calculation

Air pollutant emissions associated with bulk storage tank cleaning result from the vaporization of the organic liquid stored in the tank as well as the vaporization of any added distillates. When conducting a storage tank cleaning, the stock liquid is pumped out of the tank to empty it of its contents. Any emissions generated during this normal pump out, and the following idle period, if any, are accounted for as routine emissions and not calculated as specific to the tank cleaning process. Rather, the emissions specific to the tank cleaning process are the result of the purging of the tank's vapor space and the subsequent period of forced ventilation. The following equations primarily come from chapter 7 of AP-42, though some conservative assumptions have been made for simplification. The total emissions generated from bulk storage tank cleaning are estimated as follows.

$$\boldsymbol{L_{FV} = L_P + L_{CV}}$$

Equation 2-1

Where,

$\mathbf{L_{FV}}$ = Total emissions due to forced ventilation (lb)
$\mathbf{L_{P}}$ = Vapor space purge emissions associated with the first air change following the commencement of forced ventilation (lb)
$\mathbf{L_{CV}}$ = Emissions from the continued forced ventilation following the first air change (lb)

2.4.1 Vapor Space Purge Emissions

After the stock liquid is pumped from the tank, eductors, fans, or blowers are activated to remove the vapors remaining in the vapor space. This process marks the start of forced ventilation. This air change is referred to as the vapor space purge and the resultant emissions may be estimated as follows.

$$\boldsymbol{L_P = \left(\frac{P_{VA} \times V_V}{R \times T_V}\right) \times M_V \times S \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 2-2

Where,

$\mathbf{P_{VA}}$ = True vapor pressure of the exposed volatile material in the tank (psia). This is provided in Table 2-1.
$\mathbf{V_{V}}$ = Volume of the vapor space (ft^3).
R = Ideal gas constant, **10.731** (psia • ft^3 / lb-mol • °R)
$\mathbf{T_{V}}$ = Average temperature of the vapor space (°R)
$\mathbf{M_{V}}$ = Stock vapor molecular weight (lb/lb-mol). This is provided in Table 2-1.
S = Saturation factor. **A value of 0.5 may be used.**

CE = Control efficiency of the control device used, if applicable

Note that the average vapor space temperature (T_V) is measured in degrees Rankine (°R). To convert from degrees Fahrenheit (°F) to degrees Rankine (°R), use the following equation:

$$T_V(°R) = T_V(°F) + 459.67$$

Table 2-1. Properties of Various Fuels

Petroleum Liquid	Liquid Molecular Weight, M_L (lb/lb-mol)	Vapor Molecular Weight, M_V (lb/lb-mol)	True Vapor Pressure (psia)						
			40°F	50°F	60°F	70°F	80°F	90°F	100°F
Crude Oil RVP 5 [a]	207	50	1.8	2.3	2.8	3.4	4	4.8	5.7
Gas RVP 6	92	69	1.9	2.37	2.93	3.6	4.38	5.29	6.35
Gas RVP 7	92	68	2.3	2.9	3.5	4.3	5.2	6.2	7.4
Gas RVP 7.8	92	68	2.59	3.21	3.94	4.79	5.79	6.96	8.3
Gas RVP 8	92	68	2.67	3.3	4.04	4.92	5.94	7.13	8.5
Gas RVP 8.3	92	68	2.79	3.44	4.22	5.13	6.19	7.42	8.83
Gas RVP 9	92	67	3.06	3.77	4.61	5.59	6.74	8.06	9.58
Gas RVP 10	92	66	3.4	4.2	5.2	6.2	7.4	8.8	10.5
Gas RVP 11	92	65	3.87	4.75	5.77	6.96	8.34	9.92	11.74
Gas RVP 11.5	92	65	4.09	5	6.07	7.31	8.75	10.41	12.29
Gas RVP 12	92	64	4.29	5.24	6.36	7.65	9.15	10.86	12.82
Gas RVP 13	92	62	4.7	5.7	6.9	8.3	9.9	11.7	13.8
Gas RVP 13.5	92	62	4.93	6.01	7.26	8.71	10.38	12.29	14.46
Gas RVP 15	92	60	5.58	6.77	8.16	9.77	11.61	13.71	16.09
Diesel	188	130	3.10E-03	4.50E-03	6.50E-03	9.00E-03	1.20E-02	1.60E-02	2.20E-02
JP-8/Jet A [b]	162	130	1.58E-02	2.19E-02	3.01E-02	4.08E-02	5.48E-02	7.27E-02	9.54E-02

SOURCE (unless otherwise stated): TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005.

a. SOURCE: Section 7.1- “Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006.

b. SOURCE: “JP-8 Volatility Study,” Southwest Research Institute, March 2001. Vapor pressures calculated using the composite data calculation, an average flash point temperature of 118.238°F, and atmospheric pressure of 760mmHg. Flash point temperature average provided by “Petroleum Quality Information System Fuels Data (2005),” Defense Logistics Agency, Defense Energy Support Center, Technology and Standardization Division, 2006.

Calculation of the vapor space volume is different for fixed roof versus floating roof tanks, since the vapor space volume for a fixed roof also includes the volume of space above the cylindrical shell of the tank and below the cone or dome-shaped roof. Assuming the storage tank is cylindrical, the vapor space volume may be calculated using the following equation.

$$V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

Equation 2-3

Where,

D = Tank diameter (ft)

H = Vapor space height (ft). For fixed roofs, this is the difference between the tank shell height and the liquid height and sludge. For floating roofs, this is the vapor space under the floating roof.

H_{RO} = Roof outage (ft). For floating roof tanks, this value is 0. For fixed roof tanks, this value is calculated differently depending on the roof geometry. See Equation 2-4 or Equation 2-5 for calculation.

For a cone roof, the roof outage is calculated as follows.

$$H_{RO} = \frac{1}{6} \times S_R \times \mathrm{D}$$

Equation 2-4

Where,

S_R = Roof slope (ft/ft). A standard value of 0.0625 may be used if unknown.

For a dome roof, the outage is calculated as follows.

$$H_{RO} = \left(R_R - \sqrt{R_R^2 - R_S^2}\right) \times \left[\frac{1}{2} + \frac{1}{6} \times \left[\frac{\left(R_R - \sqrt{R_R^2 - R_S^2}\right)}{R_S}\right]^2\right]$$

Equation 2-5

Where

R_R = Tank dome roof radius (ft)

2.4.1.1 Calculation of Vapor Space Purge Emissions After Distillate Flushing

When the storage tank has been drained and the vapor space has been initially purged, the tank may be flushed using a light distillate to aid in the removal of accumulated sludge. After this distillate flushing, the vapor space is once again purged, though the values of P_{VA} and M_V used in Equation 2-2 will have changed from the initial values of the stock liquid because the remaining liquid is now a mixture of the stock and distillate. In the instance where distillate (or any other solvent) is applied to remove sludge during tank cleaning, take the following steps to correct the vapor pressure of the remaining mixture to estimate emissions resulting from this second vapor space purge:

<u>Step 1</u> **– Calculate the volume of each component in the mixture**. First, estimate the depth of the liquid heel of the stock liquid and the depth of the applied distillate. Using this depth and the interior dimensions of the tank, calculate the volume of each liquid as follows.

$$V_i = h_i \times \frac{\pi \times D^2}{4}$$

Equation 2-6

Where,

V_i = Volume of stock liquid or distillate (ft^3)
h_i = Depth of stock liquid or distillate (ft)
D = Diameter of the tank (ft)

<u>Step 2</u> – Calculate the mass of each component in the mixture. Using the volume calculated in the previous step, calculate the mass of each liquid by taking the product of their volumes and their respective densities.

$$M_i = V_i \times \rho_i \times 7.48$$

Equation 2-7

Where,

M_i = Mass of stock liquid or distillate (lb)
ρ_i = Density of stock liquid or distillate (lb/gal)
7.48 = Conversion factor converting cubic feet to gallons (gal/ft^3)

<u>Step 3</u> – Determine the number of moles of each component in the mixture. The moles of each component are calculated by taking the mass calculated in the previous step and dividing by the respective liquid molecular weight as follows.

$$n_i = \frac{M_i}{M_L}$$

Equation 2-8

Where,

n_i = Number of moles of stock liquid or distillate remaining in the tank (mol)
M_L = Liquid molecular weight of the stock liquid or distillate (lb/mol)

<u>Step 4</u> – Determine the mole (volume) fractions of each component in the mixture. This is calculated by taking the moles of each component and dividing by the total moles in the liquid mixture as shown.

$$x_i = \frac{n_i}{n_{tot}}$$

Equation 2-9

Where,

x_i = Mol fraction of stock liquid or distillate
n_{tot} = Total amount of all constituents in the mixture (mol)

Step 5 – Calculate the partial pressure of each component in the mixture. The partial pressure of each component is the product of the component mol fraction and the respective true vapor pressure.

$$P_i = x_i \times P_{VA}$$

Equation 2-10

Where,

Pi = Partial pressure of stock liquid or distillate (psia)

Step 6 – Calculate the vapor space purge emissions. Substitute the value of P_i from the previous step for P_{VA} into Equation 2-2 to get L_P for each component and sum both for the total vapor space purge emissions of the mixture for this step of the storage tank cleaning.

$$\sum_{i}^{n} (L_P)_i$$

Equation 2-11

2.4.2 Continued Forced Ventilation Emissions

After the storage tank has been drained and the vapor space purged, there may still be some volatile materials remaining. These materials will continue to generate vapors, and generally the eductors, fans, or blowers used to purge the vapor space will be activated again. This marks the beginning of the continued forced ventilation process. The vapor concentration may be monitored during this time for safety purposes and are often reported as a percent of the lower explosive limit, or %LEL. Emissions generated during this portion of the bulk storage tank cleaning process depend upon the ventilation rate and the length of time of the continued forced ventilation operation. An estimate of the generated emissions may be calculated as follows.

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

Equation 2-12

Where,

Q_V = Average ventilation rate (ft^3/min)

n_{CV} = Duration of the continued forced ventilation (days)

t_V = Daily period of forced ventilation (hr/day)

C_V = Average vapor concentration by volume. May either be taken from an organic vapor analyzer or toxic vapor analyzer that provides a direct reading of the volume concentration. If %LEL readings are available, this term may be calculated as given in Equation 2-13.

P_a = Atmospheric pressure at the tank location (psia)
M_{CG} = Calibration gas molecular weight (lb/lb-mole)
R = Ideal gas constant, **10.731** (psia • ft^3 / lb-mol • °R)

$$C_V = \left(\frac{\%LEL_{avg} \times \%LEL_{CG}}{100}\right) \times RF$$

Equation 2-13

Where,

%LEL = Average %LEL readings by measurement device
$\%LEL_{CG}$ = %LEL of the gas used to calibrate the LEL monitor
100 = Factor converting percent to a fraction (%)
RF = Response factor. Use 1.0 if unknown.

Note that the emissions generated from continued forced ventilation should be compared to an upper limit of emissions to avoid unnecessarily conservative estimates. The upper limit of emissions generated from continued forced ventilation is dependent upon whether the tank contains free standing stock liquid or volatile sludge. If the tank does contain free standing stock liquid, the upper limit may be expressed as follows.

$$L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

Equation 2-14

Where,

5.9 = Equation constant (gal/ft^3)
h_{le} = Effective height of the stock liquid. This is an estimate of the depth of the remaining liquid in the tank and sump if spread across the entire tank bottom.
W_l = Density of the stock liquid (lb/gal)

After the free-standing stock liquid has been drained, any remaining sludge will consist of non-volatile material. The upper limit of emissions in this instance is given as follows.

$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_S \times W_l$$

Equation 2-15

Where,

0.49 = Equation constant (gal/in•ft^2)
F_e = Fraction of the sludge with the potential to evaporate. **Use 0.20 if unknown.**
d_S = Average sludge depth (in)

2.5 Information Resources

For a complete list of storage tanks located on base, as well as information concerning the content of each tank, contact the Base Supply Fuels Management or Civil Engineering Liquid

Fuels shop. These offices should also be able to provide necessary tank characteristic data, such as tank type, dimensions, volume, and tank condition. For information pertaining to fuel service stations, it may be necessary to also contact the service station supervisor.

2.6 Example Problems

2.6.1 Problem #1 - Tank Cleaning Without Distillate Flushing

A DAF Base is looking at calculating emissions from the cleaning of one of their gasoline (RVP 7.8, density 6.15 lb/gal) storage tanks located on base. The tank is a fixed cone roof, flat bottom tank with a diameter of 60 feet, and a height of 20 feet. After the tank is drained, cleaning commenced with a vapor space purge where the emissions were routed to a control device with a 94% control efficiency. At the start of forced ventilation, one inch of gasoline is conservatively assumed to remain at the bottom of the tank. Another 3 inches is assumed to remain in the bottom of a 24-inch sump. Additionally, half an inch of wet sludge remains. The forced ventilation operated at 1,800 cubic feet per minute (cfm) with the emissions still routed to the control device. An average vapor concentration over this period was measured at 28,000 ppmv and the calibration gas molecular weight is 16.04 lb/lb-mol. After 24 hours, the control device was disconnected, and the tank was ventilated to the atmosphere while the forced ventilation continued. During this time, the sludge, estimated to now be a quarter of an inch, was removed and the tank was rinsed. After 8 hours, the tank was deemed to be clean and vapor free. The average vapor concentration for this day was measured at 1,500 ppmv. Assuming an average temperature of 70°F and pressure of 14.7 psia for both days, calculate the total emissions generated from this tank cleaning event.

<u>Step 1</u> – Calculate the roof outage. Prior to calculation of the emissions due to the vapor space purge, the total vapor space volume must be determined. The initial step in calculating this value is the determination of the roof outage. The problem stated that the tank has a fixed cone roof. A slope was not provided; therefore, a typical value of **0.0625ft/ft** may be used. Using this value and the stated tank diameter of **60ft**, the roof outage is calculated using Equation 2-4.

$$H_{RO} = \frac{1}{6} \times S_R \times \mathrm{D}$$

$$H_{RO} = \frac{1}{6} \times 0.0625 \frac{ft}{\cancel{ft}} \times 60\cancel{\mathrm{ft}}$$

$$\boldsymbol{H_{RO}} = \frac{1}{6} \times 3.75ft = \mathbf{0.625ft}$$

<u>Step 2</u> – Determine the vapor space height. The problem stated that after being drained, an inch of gasoline remains. With a shell height of **20ft**, the vapor space height is estimated as follows:

$$\mathrm{H} = 20ft - \frac{1\cancel{in}}{12\cancel{\mathrm{in}}/\mathrm{ft}}$$

$$\boldsymbol{H} = 20ft - 0.0833\ ft = \mathbf{19.917}\ \boldsymbol{ft}$$

Step 3 – **Calculate the vapor space volume.** With the roof outage calculated in Step 1 and vapor space height calculated in Step 2, the vapor space volume may be calculated using Equation 2-3 as follows:

$$V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

$$V_V = \frac{\pi \times 60^2 ft^2}{4} \times (19.917\ ft + 0.625\ \mathrm{ft})$$

$$\boldsymbol{V_V} = \frac{\pi \times 60^2 ft^2}{4} \times (20.542\ \mathrm{ft}) = \mathbf{58,080.19}\ \boldsymbol{ft^3}$$

Step 4 – **Identify and record the vapor molecular weight and true vapor pressure.** Vapor space purge emissions are dependent upon the characteristics of the fuel. Given that the problem stated that the average temperature was 70°F, the vapor molecular weight and true vapor pressure, according to Table 2-1, for gasoline with a Reid vapor pressure (RVP) of 7.8 are **68 lb/lb-mol** and **4.79 psia** respectively.

Step 5 - **Calculate the vapor space purge emissions.** The emissions generated during the vapor space purge are those that occur initially when the blowers were activated on the tank. The total emitted product is determined using Equation 2-2 and the calculated and recorded parameters as shown:

$$L_P = \left(\frac{P_{VA} \times V_V}{R \times T_V}\right) \times M_V \times S \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_P = \left(\frac{4.79 \times 58{,}080.19}{10.731 \times 529.67}\right) \frac{psia\ ft^3 lb{-}mol\ {}^\circ R}{psia\ ft^3 {}^\circ R} \times 68 \frac{lb}{lb{-}mol} \times 0.5 \times [1 - (0.94)]$$

$$L_P = \left(\frac{4.79 \times 58{,}080.19}{10.731 \times 529.67}\right) \frac{\cancel{psia\ ft^3} lb{-}mol\ \cancel{{}^\circ R}}{\cancel{psia\ ft^3 {}^\circ R}} \times 68 \frac{lb}{lb{-}mol} \times 0.5 \times [0.06]$$

$$L_P = (48.95) \cancel{\mathrm{lb-mol}} \times 68 \frac{lb}{\cancel{lb{-}mol}} \times 0.5 \times [0.06]$$

$$\boldsymbol{L_P} = 3{,}328.33\ lb \times 0.5 \times 0.06 = \mathbf{99.85}\ \boldsymbol{lb}$$

Step 6 – **Calculate the effective height of the remaining stock liquid and sludge.** At the start of the continued forced ventilation, an estimated height of one inch of gasoline is remaining. Additionally, it is stated that another 3 inches of fuel are in a 24-inch diameter sump. The effective height is estimated by first estimating the equivalent depth of the gasoline in the sump and then adding this to the gasoline remaining at the bottom of the tank as follows:

$$h_s = depth \times \frac{D_S^2}{D_T^2}$$

$$h_s = \frac{3\,\cancel{in}}{12^{\cancel{in}}/_{ft}} \times \frac{\left(24\,\cancel{in}/_{12\cancel{in}/ft}\right)^2}{(60\,ft)^2} = 0.00028\,ft$$

$$\boldsymbol{h_{le}} = 0.00028 \text{ ft} + \frac{1\,\cancel{in}}{12^{\cancel{in}}/_{ft}} = \mathbf{0.0836}\,\boldsymbol{ft}$$

<u>Step 7</u> – Calculate the upper limit of the emissions from the continued ventilation for the first 24 hours. This is done using Equation 2-14 as follows:

$$L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

$$L_{CV} \leq 5.9\frac{gal}{ft^3} \times (60\,ft)^2 \times 0.0836 \text{ ft} \times 6.15\frac{lb}{gal}$$

$$L_{CV} \leq 5.9\frac{gal}{\cancel{ft^3}} \times 300.96\,\cancel{ft^3} \times 6.15\frac{lb}{gal}$$

$$\boldsymbol{L_{CV}} \leq 1775.664\,\cancel{\text{gal}} \times 6.15\frac{lb}{\cancel{gal}} = \mathbf{10{,}920.33}\,\boldsymbol{lb}$$

<u>Step 8</u> – Calculate the emissions from the continued ventilation for the first 24 hours and compare to the upper limit calculated above. Note that, during this time, the ventilated air is still flowing through a control device. Using Equation 2-12 and the data provided in the problem statement, the emissions generated from the continued ventilation during the first day are calculated as follows:

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{CV} = 60\frac{min}{hr} \times 1800\frac{ft^3}{min} \times 1\,day \times 24\frac{hr}{day} \times \frac{28{,}000}{10^6} \times \\ \left(\frac{14.7\,psia \times 16.04\text{ lb•lb−mol•°R}}{10.731\,psia•ft^3 \times (70+459.67)°R•lb{-}mol}\right) \times \left[1 - \left(\frac{94\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$L_{CV} = 60\frac{min}{hr} \times 1800\frac{ft^3}{min} \times 1\,day \times 24\frac{hr}{day} \times \frac{28{,}000}{10^6} \times \\ \left(\frac{14.7\,\cancel{psia} \times 16.04\text{ lb•}\cancel{\text{lb−mol}}\text{•°R}}{10.731\,\cancel{psia}•ft^3 \times 529.67\cancel{°R•lb{-}mol}}\right) \times [1 - (.94)]$$

$$L_{CV} = 60\frac{\cancel{min}}{\cancel{hr}} \times 1800\frac{ft^3}{\cancel{min}} \times 1\,\cancel{day} \times 24\frac{\cancel{hr}}{\cancel{day}} \times \frac{28{,}000}{10^6} \times \left(\frac{0.0415\text{ lb}}{ft^3}\right) \times [0.06]$$

$$\boldsymbol{L_{CV}} = 72{,}576\,\cancel{ft^3} \times \left(\frac{0.0415\text{ lb}}{\cancel{ft^3}}\right) \times [0.06] = \boldsymbol{180.71\ lb} \leq 10{,}920.33\ lb\ ✓$$

<u>Step 9</u> – Calculate the upper limit of the emissions from the continued ventilation for the remaining time. This is done using Equation 2-15 as follows:

$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_S \times W_l$$

$$L_{CV} \leq 0.49\frac{gal}{\cancel{in}\bullet\cancel{ft^2}} \times 0.20 \times (60\,\cancel{ft})^2 \times 0.25\,\cancel{in} \times 6.15\ \frac{lb}{gal}$$

$$\boldsymbol{L_{CV}} \leq 441\ \cancel{\text{gal}} \times 0.20 \times 6.15\ \frac{lb}{\cancel{gal}} = \boldsymbol{542.43\ lb}$$

<u>Step 10</u> – Calculate the emissions from the continued ventilation for the remaining time and compare to the upper limit calculated above. Note that, during this time, the ventilated air is no longer flowing through a control device. Using Equation 2-12 and the data provided in the problem statement, the emissions generated from the continued ventilation during the remaining time are calculated as follows:

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{CV} = 60\frac{min}{hr} \times 1800\frac{ft^3}{min} \times 1\,day \times 8\frac{hr}{day} \times \frac{1{,}500}{10^6} \times \left(\frac{14.7\,\cancel{psia} \times 16.04\text{ lb}\bullet\cancel{\text{lb}-\text{mol}}\bullet{}^\circ\text{R}}{10.731\,\cancel{psia}\bullet ft^3 \times 529.67\cancel{{}^\circ R}\bullet\cancel{lb-mol}}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$L_{CV} = 60\frac{\cancel{min}}{\cancel{hr}} \times 1800\frac{ft^3}{\cancel{min}} \times 1\,\cancel{day} \times 8\frac{\cancel{hr}}{\cancel{day}} \times \frac{1{,}500}{10^6} \times \left(\frac{0.0415\text{ lb}}{ft^3}\right)$$

$$\boldsymbol{L_{CV}} = 1296\,\cancel{ft^3} \times \left(\frac{0.0415\text{ lb}}{\cancel{ft^3}}\right) = \boldsymbol{53.78\ lb} \leq 542.43\ lb\ ✓$$

<u>Step 11</u> – Calculate the total emissions from this bulk storage tank cleaning event. Sum the emissions from the vapor space purge and continued ventilation using Equation 2-1 as follows:

$$L_{FV} = L_P + L_{CV}$$

$$L_{FV} = 99.85\ lb + (180.71 + 53.78)\ lb$$

$$\boxed{\boldsymbol{L_{FV} = 334.34\ lb}}$$

2.6.2 Problem #2 – Tank Cleaning with Distillate Flushing

Assume a storage tank is cleaned using a similar process and the same information as given in Problem #1. However, in this case, assume that after the initial purge, the tank is flushed with diesel fuel (7.14 lb/gal) that equates to about four inches in total depth. Forced ventilation resumed and continued overnight and into the second day (for a total of 18 hours) while still connected to the control device. At the start of the second day, the gasoline/diesel mixture is vacuumed out, leaving a half inch of wet sludge. Forced ventilation resumes after disconnecting the control device and continues for 8 hours while the sludge is removed. At the end of the second day, the forced ventilation was turned off and the average vapor concentration was calculated as 4,400 ppmv. Approximately 1/8 inch of wet sludge was estimated to remain. Finally, at the start of the third day, forced ventilation resumed while the remaining sludge was removed. Forced ventilation was terminated after 8 hours and the average vapor concentration was calculated as 1,000 ppmv. The tank was rinsed and completely clean by the end of the third day. The temperature and pressure recorded for the third day remained steady at 70°F and 14.7 psia respectively.

__Step 1__ **– Calculate the roof outage, vapor space height, vapor space volume and calculate the vapor space purge emissions for the first day.** Since the tank dimensions and the temperature and pressure measurements in this problem are the same as given in Problem #1, this initial step is the same as Steps 1 -5 from Problem #1. The total calculated emissions from the first day's vapor space purge were calculated as **99.85 lb**.

__Step 2__ **– Calculate the upper limit of the emissions from the continued ventilation for the first 24 hours.** In this problem, distillate was added to flush the tank. The total diesel added was determined to be equivalent to 4 inches in depth. Using this value, the given density of the diesel (**7.14 lb/gal**) the density of the gasoline as given in Problem #1 (**6.15 lb/gal**), and the effective height of the gasoline as calculated in Step 6 of Problem # 1 (**0.0836 ft**) the upper limit is calculated using Equation 2-14 as follows:

$$L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

$$L_{CV} \leq 5.9 \frac{gal}{ft^3} \times (60\ ft)^2 \times \left[\left(0.0836\ \text{ft} \times 6.15 \frac{lb}{gal}\right) + \left(\frac{4\ \cancel{in}}{12 \cancel{in}/_{ft}} \times 7.14 \frac{lb}{gal}\right)\right]$$

$$L_{CV} \leq 5.9 \frac{gal}{ft^3} \times (60\ ft)^2 \times \left[\left(2.894 \frac{ft\ lb}{gal}\right)\right]$$

$$L_{CV} \leq 5.9 \frac{gal}{ft^3} \times 3600 ft^2 \times \left(2.894 \frac{ft\ lb}{gal}\right)$$

$$\boldsymbol{L_{CV}} \leq 5.9\frac{\cancel{gal}}{\cancel{ft^3}} \times 10{,}418.4\frac{\cancel{ft^3}\,lb}{\cancel{gal}} = \mathbf{61,468.56}\ \boldsymbol{lb}$$

__Step 3__ – **Calculate the emissions from the continued ventilation for the first 24 hours and compare to the upper limit calculated above.** Note that, during this time, the ventilated air is still flowing through a control device. Using Equation 2-12 and the data provided in the problem statement, the emissions generated from the continued ventilation during the first day are calculated as follows:

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{CV} = 60\frac{min}{hr} \times 1800\frac{ft^3}{min} \times 1\ day \times 18\frac{hr}{day} \times \frac{28{,}000}{10^6} \times \left(\frac{14.7\ psia \times 16.04\ \text{lb•lb−mol•°R}}{10.731\ psia\,•ft^3 \times (70+459.67)°R\,•lb-mol}\right) \times \left[1 - \left(\frac{94\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$L_{CV} = 60\frac{min}{hr} \times 1800\frac{ft^3}{min} \times 1\ day \times 18\frac{hr}{day} \times \frac{28{,}000}{10^6} \times \left(\frac{14.7\ \cancel{psia} \times 16.04\ \text{lb•}\cancel{\text{lb−mol}}\text{•°R}}{10.731\ \cancel{psia}\,•ft^3 \times 529.67\cancel{°R}\,•\cancel{lb-mol}}\right) \times [1 - (.94)]$$

$$L_{CV} = 60\frac{\cancel{min}}{\cancel{hr}} \times 1800\frac{ft^3}{\cancel{min}} \times 1\ \cancel{day} \times 18\frac{\cancel{hr}}{\cancel{day}} \times \frac{28{,}000}{10^6} \times \left(\frac{0.0415\ \text{lb}}{ft^3}\right) \times [0.06]$$

$$\boldsymbol{L_{CV}} = 54{,}432\ \cancel{ft^3} \times \left(\frac{0.0415\ \text{lb}}{\cancel{ft^3}}\right) \times [0.06] = \mathbf{135.54}\ \boldsymbol{lb} \leq 61{,}468.56\ lb\ \checkmark$$

__Step 4__ – **Calculate the upper limit of the emissions from the continued ventilation for the second day.** Note that, in this example problem there is both gasoline and diesel remaining in the tank. However, since the density of the diesel fuel is greater than that of gasoline (7.14 vs 6.15 lb/gal) and the remaining liquid is comprised of more diesel than gasoline, it would be acceptable to calculate a conservative upper limit using the density of the diesel fuel. The conservative upper limit is therefore calculated using Equation 2-15 as follows:

$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_S \times W_l$$

$$L_{CV} \leq 0.49\frac{gal}{\cancel{in}\,•\cancel{ft^2}} \times 0.20 \times (60\ \cancel{ft})^2 \times 0.5\ \cancel{in} \times 7.14\ \frac{lb}{gal}$$

$$\boldsymbol{L_{CV}} \leq 882\ \text{gal} \times 0.20 \times 7.14\frac{lb}{\cancel{gal}} = \mathbf{1,259.5}\ \boldsymbol{lb}$$

__Step 5__ – **Calculate the emissions from the continued ventilation for the second day and compare to the upper limit calculated above.** Note that, during this time, the ventilated air is no longer flowing through a control device. Using Equation 2-12 and the data provided in the problem statement, the emissions generated from the continued ventilation during the remaining time are calculated as follows:

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{CV} = 60\,\frac{min}{hr} \times 1800\,\frac{ft^3}{min} \times 1\,day \times 8\,\frac{hr}{day} \times \frac{4{,}400}{10^6} \times \left(\frac{14.7\,\cancel{psia} \times 16.04\ \text{lb}\bullet\cancel{\text{lb-mol}}\bullet{}^{\circ}\text{R}}{10.731\,\cancel{psia}\bullet ft^3 \times 529.67\cancel{{}^{\circ}R}\bullet\cancel{lb-mol}}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$L_{CV} = 60\,\frac{\cancel{min}}{\cancel{hr}} \times 1800\,\frac{ft^3}{\cancel{min}} \times 1\,\cancel{day} \times 8\,\frac{\cancel{hr}}{\cancel{day}} \times \frac{4{,}400}{10^6} \times \left(\frac{0.0415\ \text{lb}}{ft^3}\right)$$

$$\boldsymbol{L_{CV}} = 3{,}801.6\,\cancel{ft^3} \times \left(\frac{0.0415\ \text{lb}}{\cancel{ft^3}}\right) = \mathbf{157.77\ lb} \leq 1{,}259.5\ lb\ \checkmark$$

<u>Step 6</u> – Calculate the volume of each component in the mixture. Though most of the diesel and gas mixture was vacuumed out the second day, a conservative estimate using their respective depths (0.0836 ft for gasoline as calculated in Step 6 of Problem#1) and the tank dimensions may be used to estimate their respective volumes using Equation 2-6.

$$V_i = h_i \times \frac{\pi \times D^2}{4}$$

$$\boldsymbol{V_{gasoline}} = 0.0836\,ft \times \frac{\pi \times (60\,ft)^2}{4} = \mathbf{236.37\,ft^3}$$

$$\boldsymbol{V_{diesel}} = \frac{4\,\cancel{in}}{12^{\cancel{in}}/_{ft}} \times \frac{\pi \times (60\,ft)^2}{4} = \mathbf{942.48\,ft^3}$$

<u>Step 7</u> – Calculate the mass of each component in the mixture. Using the volume calculated above, their respective densities, and Equation 2-7, the mass of each is estimated as follows:

$$M_i = V_i \times \rho_i \times 7.48$$

$$\boldsymbol{M_{gasoline}} = 236.37\cancel{ft^3} \times 6.15\,\frac{lb}{\cancel{gal}} \times 7.48\,\frac{\cancel{gal}}{\cancel{ft^3}} = \mathbf{10{,}873.49\ lb}$$

$$\boldsymbol{M_{diesel}} = 942.48\cancel{ft^3} \times 7.14\,\frac{lb}{\cancel{gal}} \times 7.48\,\frac{\cancel{gal}}{\cancel{ft^3}} = \mathbf{50{,}335.22\ lb}$$

<u>Step 8</u> – Determine the number of moles of each component in the mixture. Using Equation 2-8 and the liquid molecular weights of each component, as given in Table 2-1 (**92 lb/lb-mol** for gasoline and **188 lb/lb-mol** for diesel), the number of moles of each component is calculated as follows:

$$n_i = \frac{M_i}{M_L}$$

$$\boldsymbol{n_{gasoline}} = \frac{10{,}873.49 \text{ lb}}{92\ lb/_{lb-mol}} = \mathbf{118.19}\ \boldsymbol{moles}$$

$$\boldsymbol{n_{diesel}} = \frac{50{,}335.22 \text{ lb}}{188\ lb/_{lb-mol}} = \mathbf{267.74}\ \boldsymbol{moles}$$

<u>Step 9</u> – Determine the mole (volume) fractions of each component in the mixture. Using Equation 2-9, the mole fractions of each component are determined as follows:

$$x_i = \frac{n_i}{n_{tot}}$$

$$\boldsymbol{x_{gasoline}} = \frac{118.19\ \cancel{\text{mol}}}{(118.19+267.74)\ \cancel{moles}} = \mathbf{0.306}$$

$$\boldsymbol{x_{diesel}} = \frac{267.74\ \cancel{\text{mol}}}{(118.19+267.74)\ \cancel{moles}} = \mathbf{0.694}$$

<u>Step 10</u> – Calculate the partial pressure of each component in the mixture. First, the true vapor pressure of each component at the specified temperature (70°F) is recorded from Table 2-1. For gasoline (RVP 7.8) this is **4.79 psia** and for diesel it is **0.009 psia**. Using Equation 2-10, the partial pressures from each component are calculated as follows:

$$P_i = x_i \times P_{VA}$$

$$\boldsymbol{P_{gasoline}} = 0.306 \times 4.79 \text{ psia} = \mathbf{1.466\ psia}$$

$$\boldsymbol{P_{diesel}} = 0.694 \times 0.009 \text{ psia} = \mathbf{0.00625\ psia}$$

<u>Step 11</u> – Calculate the vapor space volume. At this point in the cleaning process, the mixture has been removed and only the sludge remains. Ignoring the depth of the sludge, the vapor space volume may be calculated using Equation 2-3 as follows:

$$V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

$$V_V = \frac{\pi \times 60^2 ft^2}{4} \times (20\ ft + 0.625 \text{ ft})$$

$$\boldsymbol{V_V} = \frac{\pi \times 60^2 ft^2}{4} \times (20.625\text{ ft}) = \mathbf{58,315.81}\ \boldsymbol{ft^3}$$

<u>Step 12</u> – Calculate the vapor space purge emissions from each component from the third day. Since the forced ventilation was shut off at the end of the second day, vapors from both the gasoline and diesel accumulated within the vapor space. Once the fans are restarted, the initial purge results in emissions from each component. Those emissions are estimated using Equation 2-2 as follows:

$$L_P = \left(\frac{P_{VA} \times V_V}{R \times T_V}\right) \times M_V \times S \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{P\ Gasoline} = \left(\frac{1.466 \times 58{,}315.81}{10.731 \times 529.67}\right) \frac{psia\ ft^3 lb{-}mol\ {}^\circ R}{psia\ ft^3 {}^\circ R} \times 68 \frac{lb}{lb{-}mol} \times 0.5 \times [1 - (0)]$$

$$L_{P\ Gasoline} = \left(\frac{1.466 \times 58{,}315.81}{10.731 \times 529.67}\right) \frac{\cancel{psia}\ \cancel{ft^3} lb{-}mol\ \cancel{{}^\circ R}}{\cancel{psia}\ \cancel{ft^3 {}^\circ R}} \times 68 \frac{lb}{lb{-}mol} \times 0.5$$

$$\boldsymbol{L_{P\ Gasoline}} = (15.04)\cancel{\text{lb} - \text{mol}} \times 68 \frac{lb}{\cancel{lb{-}mol}} \times 0.5 = \mathbf{511.36\ lb}$$

$$L_{P\ Diesel} = \left(\frac{0.00625 \times 58{,}315.81}{10.731 \times 529.67}\right) \frac{psia\ ft^3 lb{-}mol\ {}^\circ R}{psia\ ft^3 {}^\circ R} \times 130 \frac{lb}{lb{-}mol} \times 0.5 \times [1 - (0)]$$

$$L_{P\ Diesel} = \left(\frac{0.00625 \times 58{,}315.81}{10.731 \times 529.67}\right) \frac{\cancel{psia}\ \cancel{ft^3} lb{-}mol\ \cancel{{}^\circ R}}{\cancel{psia}\ \cancel{ft^3 {}^\circ R}} \times 130 \frac{lb}{lb{-}mol} \times 0.5$$

$$\boldsymbol{L_{P\ Diesel}} = (0.064)\cancel{\text{lb} - \text{mol}} \times 130 \frac{lb}{\cancel{lb{-}mol}} \times 0.5 = \mathbf{4.17\ lb}$$

<u>Step 13</u> - Calculate the vapor space purge emissions. The total vapor space emissions generated on the third day are the sum from each component and is calculated as follows:

$$\sum_{i}^{n} (L_P)_i = (511.36 + 4.17) lb = \mathbf{515.53}\ \boldsymbol{lb}$$

<u>Step 14</u> – Calculate the upper limit of the emissions from the continued ventilation for the remaining time. This is done using Equation 2-15 as follows:

$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_S \times W_l$$

$$L_{CV} \leq 0.49 \frac{gal}{\cancel{in \bullet ft^2}} \times 0.20 \times (60\ \cancel{ft})^2 \times 0.125\ \cancel{in} \times 7.14\ \frac{lb}{gal}$$

$$\boldsymbol{L_{CV}} \leq 220.5\ \cancel{\text{gal}} \times 0.20 \times 7.14\ \frac{lb}{\cancel{gal}} = \mathbf{314.87}\ \boldsymbol{lb}$$

<u>Step 15</u> – Calculate the emissions from the continued ventilation for the remaining time and compare to the upper limit calculated above. Note that, during this time, the ventilated air is no longer flowing through a control device. Using Equation 2-12 and the data provided in the problem statement, the emissions generated from the continued ventilation during the remaining time are calculated as follows:

$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V}\right) \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$L_{CV} = 60\,\frac{min}{hr} \times 1800\,\frac{ft^3}{min} \times 1\,day \times 8\,\frac{hr}{day} \times \frac{1{,}000}{10^6} \times \left(\frac{14.7\,\cancel{psia} \times 16.04\ \mathrm{lb}\bullet\cancel{\mathrm{lb-mol}}\bullet{}^\circ\mathrm{R}}{10.731\,\cancel{psia}\bullet ft^3 \times 529.67\cancel{{}^\circ R}\bullet\cancel{lb-mol}}\right) \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$L_{CV} = 60\,\frac{\cancel{min}}{\cancel{hr}} \times 1800\,\frac{ft^3}{\cancel{min}} \times 1\,\cancel{day} \times 8\,\frac{\cancel{hr}}{\cancel{day}} \times \frac{1{,}000}{10^6} \times \left(\frac{0.0415\ \mathrm{lb}}{ft^3}\right)$$

$$\boldsymbol{L_{CV}} = 864\,\cancel{ft^3} \times \left(\frac{0.0415\ \mathrm{lb}}{\cancel{ft^3}}\right) = \boldsymbol{35.86\ lb} \leq 314.87\ lb\ \checkmark$$

<u>Step 16</u> – Calculate the total emissions from this bulk storage tank cleaning event. Sum the emissions from the vapor space purges and continued ventilation for all three days using Equation 2-1 as follows:

$$L_{FV} = L_P + L_{CV}$$

$$L_{FV} = (99.85 + 515.53)lb + (135.54 + 157.77 + 35.86)\ lb$$

$$\boxed{\boldsymbol{L_{FV} = 944.55\ lb}}$$

2.7 References

40 CFR 63 Subpart OO, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart OO-National Emission Standards for Tanks – Level 1," U.S. Environmental Protection Agency

40 CFR 63 Subpart WW, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart WW-National Emission Standards for Storage Vessels (Tanks) – Control Level 2," U.S. Environmental Protection Agency

40 CFR 63 Subpart EEEE, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart EEEE-National Emission Standards for Hazardous Air Pollutants" Organic Liquids Distribution (Non-gasoline)," U.S. Environmental Protection Agency

40 CFR 63 Subpart CCCCCC, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for Hazardous Air Pollutants for Source Categories, Subpart CCCCCC-National Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Dispensing Facilities," U.S. Environmental Protection Agency

Mayfield 1996, "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996

USEPA 2016, "TANKS Software Frequent Questions." EPA, https://www3.epa.gov/ttnchie1/faq/tanksfaq.html#13. Accessed November 2014

USEPA 2020, Section 7.1-"Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2020

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3 BURN, OPEN (OB)

- *Fugitive* Source

3.1 Introduction

Open burning is the burning of unwanted material in the open air where smoke and emissions are released into the atmosphere directly. Open burning is generally done outdoors where waste materials are burnt as a means of waste disposal, away from an incinerator or a furnace chamber. Open burning can be done in open drums or baskets, in fields and yards, and in large open dumps or pits. **Open burning operations result in the fugitive emissions of criteria pollutants and greenhouse gases.**

3.1.1 Open Burning

Open burning is defined as the combustion of materials in unenclosed areas such as in open drums, baskets, fields, or in pits. Materials commonly disposed of in this manner include municipal waste, auto body components, landscape refuse, agricultural field refuse, wood refuse, bulky industrial refuse, and leaves. Federal regulations prohibit the open burning of hazardous waste, apart from explosive ordnance, whose emissions calculations are described in the *Air Emissions Guide for Air Force Stationary Sources*.

Emissions from the open burning of agricultural materials are dependent on the moisture content and compactness of the material as well as whether the refuse is burned in a headfire or backfire. Headfires are started at the upwind side of a field and allowed to progress in the direction of the wind whereas backfires start at the downwind edge and progress in a direction opposing the wind. How the refuse is arranged, such as in piles, rows, or spread out, can influence the emissions as well. A simple control volume for open burns is provided in Figure 3-1.

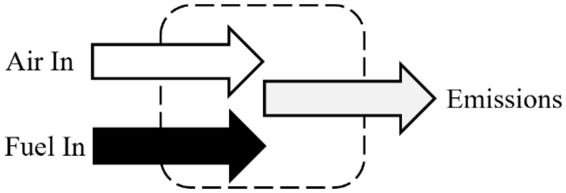


Figure 3-1. Simplified Open/Prescribed Burn Control Volume

3.2 NSPS Applicability

There are several NSPS that have been set by the EPA and apply specifically to air curtain incinerators, also known as trench combustors, which may be used for open burning purposes.

For any installation that uses air curtain incinerators, it is assumed that they combust 100 percent wood or yard waste, which exempts these incinerators from several NSPS provisions. However, there are several opacity emissions limits, testing requirements, and reporting and record keeping provisions in which these air curtain incinerators are still required to abide. Both the size of the air curtain incinerator and the date it was constructed determines the standards that may apply. The following subparts to 40 CFR 60 have provisions specific to air curtain incinerators:

- Subpart Cb – Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that are Constructed on or Before September 20, 1994
- Subpart Eb – Standards of Performance for Large Municipal Waste Combustors for Which Construction is Commenced After September 20, 1994, or for Which Modification or Reconstruction is Commenced After June 19, 1996
- Subpart AAAA – Standards of Performance for Small Municipal Waste Combustion Units for Which Construction is Commenced After August 30, 1999, or for Which Modification or Reconstruction is Commenced After June 6, 2001
- Subpart BBBB – Emission Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999
- Subpart CCCC – Standards of Performance for Commercial and Industrial Solid Waste Incineration Units
- Subpart DDDD – Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units
- Subpart EEEE – Standards of Performance for Other Solid Waste Incineration Units for Which Construction is Commenced After December 9, 2004, or for Which Modification or Reconstruction is Commenced on or After June 16, 2006
- Subpart FFFF – Emission Guidelines and Compliance Times for Other Solid Waste Incineration Units that Commenced Construction on or Before December 9, 2004

For more information regarding the standards applicable to air curtains, refer to the appropriate subpart in 40 CFR 60.

3.3 Emissions Factors

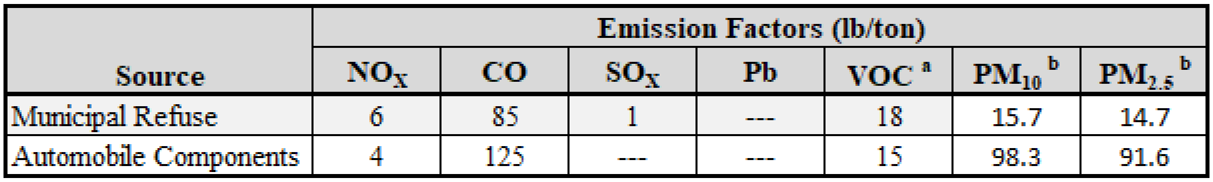
Open burning emissions are affected by many variables, including wind, ambient temperature, composition, and moisture content of the debris burned, and compactness of the pile. In general, the relatively low temperatures associated with open burning increase emissions of particulate matter, carbon monoxide, and hydrocarbons and suppress emissions of nitrogen oxides. Emissions of sulfur oxides are a direct function of the sulfur content of the refuse.

EFs have been developed for open burns based on the amount and type of material burned. Sulfur oxide emissions are a direct function of the amount of sulfur in the material burned but are typically negligible.

AP-42 also provides EFs for several types of agricultural materials in units of pounds per ton of refuse burned. Table 3-1 and Table 3-2 provide criteria pollutant EFs for the open burning of municipal refuse and agricultural materials, respectively. Table 3-2 also provides average fuel loading factors for different types of agricultural materials. The fuel loading factor is an average estimate of the amount of material burned per unit of land (e.g., acre). Refer to Chapter 2.5 of AP-42 for species specific EFs.

Air curtain incinerators may be used as an alternative to traditional open burning. The purpose of the air curtain is to reduce particulate emissions while improving the combustion efficiency by applying a curtain of air across the top of an open pit where materials are being burned. Air curtain incinerators are likely only to be used for open burning of agricultural materials. For additional information, refer to Section 2.1 of AP-42.

Table 3-1. Criteria Pollutant Emission Factors for Municipal Refuse



Source	Emission Factors (lb/ton)						
	NO_X	CO	SO_X	Pb	VOC [a]	PM_{10} [b]	$PM_{2.5}$ [b]
Municipal Refuse	6	85	1	---	18	15.7	14.7
Automobile Components	4	125	---	---	15	98.3	91.6

SOURCE (unless otherwise stated): Section 2.5 – "Open Burning, "Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

a. VOC emission factor provided is the non-methane TOC emission factor provided in source document.

b. Source document provides emission factors for PM. These values calculated using the PM10 and PM2.5 fraction from Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

Table 3-2. Criteria Pollutant Emission Factors for Open Burning of Agricultural Materials

Agricultural Material [a]	Fuel Loading Factor (ton/acre)	Emission Factors (lb/ton)						
		NO_X	CO	SO_X	Pb	VOC [b]	PM_{10} [c]	$PM_{2.5}$ [c]
Field Crops	2	---	117	---	---	18	20.66	19.70
Grasses	---	---	101	---	---	15	15.74	15.01
Leaf Burning	---	---	112	---	---	28	37.39	35.64
Orchard Crops	1.6	---	52	---	---	8	5.89	5.55
Vine Crops	2.5	---	51	---	---	5	4.92	4.69
Weeds	3.2	---	85	---	---	9	14.76	14.07
Forest Residues - Unspecified	70	4	140	---	---	19	16.34	14.52
Forest Residues - Hemlock, Douglas Fir, Cedar	---	4	90	---	---	4	3.84	3.42
Forest Residues - Ponderosa Pine	---	4	195	---	---	11	11.53	10.25
Air Curtain Incinerators								
Wood [d]	---	1	2.6	0.1	---	0.9	1.30	0.87

SOURCE (unless otherwise stated): Section 2.5 – "Open Burning, "Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

a. Unless otherwise specified, the agricultural material is "unspecified".

b. VOC emission factor provided is the non-methane TOC emission factor provided in source document.

c. Source document provides emission factors for PM. These values calculated using the PM_{10} and $PM_{2.5}$ fraction from Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

d. SOURCE: Clerico, Brian, and Errol Villegas. "Air Curtain Incinerator Emissions Factors Determination." Memo to Arnaud Marjollet, Director of Permit Services, San Joaquin Valley Air Pollution Control. 4 Apr. 2017.

"---" – No Data Available.

Table 3-3. GHG Emission Factors for Open Burning of Agricultural Materials

Agricultural Material [a]	Emission Factors (lb/ton)			
	CO_2	N_2O	CH_4 [b]	CO_2e [c]
Field Crops	2,149	0.08	5.4	2,307
Grasses	2,149	0.08	4.5	2,285
Leaf Burning	2,149	0.08	12	2,472
Orchard Crops	2,149	0.08	2.5	2,235
Vine Crops	2,149	0.08	1.7	2,215
Weeds	2,149	0.08	3.0	2,247
Forest Residues - Unspecified	3,615	0.14	5.7	3,799
Forest Residues - Hemlock, Douglas Fir, Cedar	3,615	0.14	1.2	3,686
Forest Residues - Ponderosa Pine	3,615	0.14	3.3	3,739
Air Curtain Incinerators				
Wood	3,615	0.14	0.28	3,663

SOURCE (unless otherwise stated): "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources, U.S. Environmental Protection Agency.

a. Unless otherwise stated, the refuse category is "unspecified".

b. SOURCE (excluding air curtain incinerators): Section 2.5 – "Open Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

c. CO_2e calculated by summing the product of the emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25, respectively.

3.4 Emissions Calculation

For open burning, the EFs provided above are sufficient for the general calculation of emissions. However, for enhanced accuracy, refer to Section 2.5 of AP-42 for more information regarding species or region-specific EFs.

Calculation of emissions from open burns is accomplished by taking the product of the total mass burned and the respective EF as follows:

$$\boldsymbol{E(Pol) = Q \times EF(Pol)}$$

Equation 3-1

Where,

E(Pol) = Annual emission of pollutant from open/prescribed burns (lb/yr)
Q = Annual mass of material burned (ton/yr)
EF(Pol) = Emission factor for pollutant (lb/ton)

The total annual mass of material burned is an estimated value. Best judgment should be used when making this determination. For convenience, average fuel loading factors are provided in Table 3-2 and may be used to estimate the mass burned as follows:

$$\boldsymbol{Q = A \times LF}$$

Equation 3-2

Where,

A = Area burned (acres/yr)
LF = Fuel loading factor (ton/acre)

3.5 Example Problems

3.5.1 Problem #1 (Open Burn)

Last year, a DAF Base cleared 6.5 acres of land. The agricultural material on this land was primarily weeds, which were disposed of through open burning. Calculate the CO, VOC, PM_{10}, $PM_{2.5}$, and CO_2e emissions from this operation.

Step 1 – **Select and record the fuel loading factor.** Since the quantity of weeds was not provided in the problem statement, this value must be calculated. The first step involves recording the fuel loading factor which, according to Table 3-2 is **3.2 ton/acre** for weeds.

Step 2 – **Calculate the mass burned.** Using the total land cleared, the fuel loading factor recorded in Step 1 and Equation 3-2, the mass burned is calculated as follows:

$$Q = A \times LF$$

$$\boldsymbol{Q} = 6.5\,\frac{\cancel{acre}}{yr} \times 3.2\,\frac{ton}{\cancel{acre}} = \mathbf{20.8}\,\frac{\boldsymbol{ton}}{\boldsymbol{yr}}$$

Step 3 – **Record emission factors.** According to Table 3-1 and Table 3-2, the EFs for CO, VOC, PM_{10}, $PM_{2.5}$ and CO_2e are **85, 9, 14.76, 14.07, and 2247 lb/ton,** respectively.

Step 4 – Calculate emissions. Using the mass burned as calculated in Step 2, the EFs recorded in Step 3, and Equation 3-1, the emissions of each pollutant are calculated as follows:

$$E(Pol) = Q \times EF(Pol)$$

$$E(CO) = 20.8\,\frac{\cancel{ton}}{yr} \times 85\,\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(CO) = 1{,}768\,\frac{lb}{yr}}}$$

$$E(VOC) = 20.8\,\frac{\cancel{ton}}{yr} \times 9\,\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(VOC) = 187.2\,\frac{lb}{yr}}}$$

$$E(PM_{10}) = 20.8\,\frac{\cancel{ton}}{yr} \times 14.76\,\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(PM_{10}) = 307.0\,\frac{lb}{yr}}}$$

$$E(PM_{2.5}) = 20.8\,\frac{\cancel{ton}}{yr} \times 14.07\,\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(PM_{2.5}) = 292.7\,\frac{lb}{yr}}}$$

$$E(GHG) = 20.8\,\frac{\cancel{ton}}{yr} \times 2247\,\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(GHG) = 46{,}737.6\,\frac{lb}{yr}}}$$

3.6 References

40 CFR 60 Subpart Cb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Cb-Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that are Constructed on or Before September 20, 1995," U.S. Environmental Protection Agency

40 CFR 60 Subpart Eb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Eb-Standards of Performance for Municipal Waste Combustors for which Construction is Commenced After June 19, 1996," U.S. Environmental Protection Agency

40 CFR 60 Subpart AAAA, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart AAAA-Standards of Performance for Small Municipal Waste Combustion Units for which Construction is Commenced After August 30,1999," U.S. Environmental Protection Agency

40 CFR 60 Subpart BBBB, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart BBBB-Emissions Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999," U.S. Environmental Protection Agency

40 CFR 60 Subpart CCCC, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart CCCC-Standards of Performance for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart DDDD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart DDDD-Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart EEEE, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart EEEE-Standards of Performance for Other Solid Waste Incineration Units for which Construction is Commenced After December 9, 2004, or for

which Modification or Reconstruction is Commenced on or After June 16, 2006," U.S. Environmental Protection Agency

40 CFR 60 Subpart FFFF, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart FFFF-Emissions Guidelines and Compliance Times for Other Solid Waste Incineration Units that Commenced Construction on or Before December 9, 2004," U.S. Environmental Protection Agency

40 CFR 60 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

40 CFR 98, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-

USEPA 1995, Section 2.5-"Open Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995

4 CONSTRUCTION (CNST)

- *(Primarily) Fugitive* Source – Construction Equipment and Activity

This category is not included in an AEI since, unlike the other sections of this document, it describes calculations of emissions for a proposed action, not actual emissions, which are conditionally mobile or stationary

4.1 Introduction

Emissions from construction activities may vary from day to day depending on the level of activity, the phase of the construction process, and meteorological conditions. **Emissions of concern from construction include criteria pollutants and greenhouse gases and may be either point or fugitive.** Much of the emissions from construction are the result of exhaust from motorized vehicles/equipment whose emissions calculations are described in the *Air Emissions Guide for Air Force Mobile Sources*.

The total emissions resulting from construction operations are the sum of the pollutant emitting activities that occur during each phase of construction. Emissions from construction operations include emissions of the equipment involved in the construction activity, vehicle emissions from the workers commuting to the construction site, and emissions from the activity itself. Calculating emissions from each phase involves acquiring some site data such as the area and volume of the construction activity, and the average commuting distance for the workers. Programs such as the Air Conformity Applicability Model (ACAM) or other approved models, may calculate emissions from each phase of the construction process using user input data or assumptions in lieu of site data. Many default values and algorithms for use in emissions calculations are taken from CALEEMOD and URBEMIS, emissions estimation computer programs developed for estimating emissions associated with land development projects. Vehicle exhaust emissions associated with land development projects may be estimated using their respective emission factors provided in OFFROAD. OFFROAD provides the most recent model outputs for many types of off-road equipment across several calendar years, model years, fuel, and horsepower ranges.

4.1.1 Construction Phases

Generally, each construction project is unique; therefore, there is no one systematic approach to estimating emissions associated with construction. Because of this uniqueness, the preferred Air Force method is to separate construction into typical phases that result in quantifiable emissions. Construction operations may be classified as having seven phases:

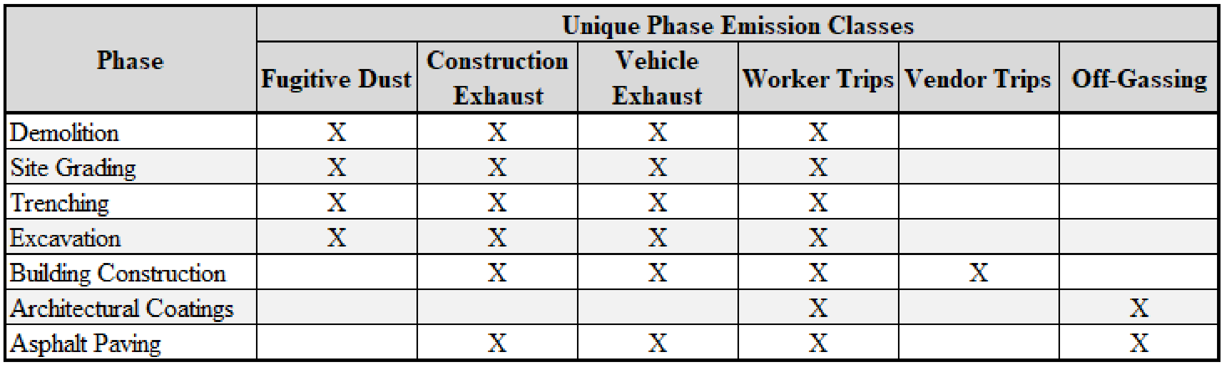
1) Demolition
2) Site Grading
3) Trenching

4) Excavation
5) Building Construction
6) Architectural Coating
7) Asphalt Paving

Each construction phase results in a unique combination of construction emission classes, as shown in Table 4-1. There are six construction emission classes that may contribute to the emissions for any specific construction phase, which include:

- Fugitive Dust,
- Construction Exhaust (Off-road equipment),
- Vehicle Exhaust (On-road vehicles),
- Worker Trips,
- Vendor Trips, and
- Off-Gassing.

Table 4-1. Summary of Construction Phases and Their Emission Classes



Phase	Unique Phase Emission Classes					
	Fugitive Dust	Construction Exhaust	Vehicle Exhaust	Worker Trips	Vendor Trips	Off-Gassing
Demolition	X	X	X	X		
Site Grading	X	X	X	X		
Trenching	X	X	X	X		
Excavation	X	X	X	X		
Building Construction		X	X	X	X	
Architectural Coatings				X		X
Asphalt Paving		X	X	X		X

An "X" in a column indicates that emission class is considered in the overall emissions calculations for the phase. For example, the "site grading" phase will consider Fugitive Dust, Construction Exhaust (Off-road equipment), Vehicle Exhaust (On-road vehicles), and Worker Trips in calculating the overall emissions associated with site grading.

<u>Demolition</u> involves the tearing down of buildings or other obstacles and moving the remaining debris off-site. Buildings may be demolished using loaders, bulldozers, demolition excavators, or using carefully placed explosives that result in building implosions.

<u>Site Grading</u> is the process of altering the slope and elevation of land. This action is performed to provide a stable base for the foundation of new construction and to improve drainage around new or existing facilities.

Excavating involves the digging and removing of soil and rock. Excavated soil may be kept on-site for filling or backfilling open cavities, and for use in site grading. Any excess excavated material not used on-site is moved to an off-site location to be used elsewhere.

Trenching while generally the same process as excavating, occurs beneath the ground's surface, and they are narrow relative to their length. Typically trenching is used when laying pipes or cables for electricity or telecommunications.

The Building Construction phase introduces several different types of equipment depending on the scope of the project. These include cranes, forklifts, and loaders. The primary difference between the building construction phase and the other phases in construction from an air emissions standpoint, is that building construction does not typically produce fugitive dust emissions. However, emissions from vehicle exhaust increases during the building construction phase. The increase in vehicle exhaust is most often attributable to the influx of vendors making product deliveries to the construction site.

Architectural Coating involves the application of paint to the surface of standing structures. Painting applications result in the release of VOCs into the atmosphere due to the evaporation of solvents in the paint. Therefore, the amount of emissions is directly correlated to the composition and volume of the paint used.

Asphalt Paving is commonly used to surface roads and parking lots. Asphalt is composed of compacted aggregate, such as sand, gravel, and crushed stone, and an asphalt binder. The asphalt binder may be either asphalt cement or liquefied asphalt. Liquefied asphalt may be either asphalt cutbacks, which is produced by dissolving the binder with volatile petroleum distillates, or emulsified asphalts, which is an environmentally friendlier alternative to cutbacks. According to AP-42, "minor amounts of VOCs are emitted from emulsified asphalts and asphalt cement". This document provides the theoretical calculation of VOCs from asphalt paving and does not provide EFs for the calculation of actual emissions. This is due to the decline in cutback asphalt use in favor of emulsified asphalt. **The EF for VOCs from emulsified asphalt and asphalt cement are essentially assumed to be zero.**

4.2 Emission Standards

To gradually decrease air emissions, the EPA has established air emission standards for nonroad engines whose full federal definition is provided in 40 CFR 1038.30. These standards, which apply to construction vehicles and equipment, establish multiple emission tiers with established compliance dates. The emission standards in which each engine must comply are based on that engine's size and year of manufacture. For more information regarding the nonroad engine standards and the year of implementation, refer to 40 CFR parts 89, 1068, and 1039.

4.3 Emissions Calculation

The construction project emissions for a specific pollutant are estimated by summing the total emissions (for the specific pollutant) for each of the six construction phases as shown below:

$$\boldsymbol{E(Pol) = \sum_{i=1}^{n} E(Pol)_i}$$

Equation 4-1

Where,

E(Pol) = Emissions of individual pollutant for entire construction project (lb)
E(Pol)i = Emissions of individual pollutant for an individual construction phase (lb)
i = Denotes the individual construction phase – i.e., Demolition, Site Grading, Trenching/Excavation, Building Construction, Architectural Coatings, or Asphalt Paving

Emissions of individual pollutants for each of the individual construction phases are estimated by summing the emissions for all the phase components:

$$\boldsymbol{E(Pol)_i = E(Pol)_{Fugitive\ Dust} + E(Pol)_{Construction\ Exhaust} + E(Pol)_{Vehicle\ Emissions} + E(Pol)_{Worker\ Trips} + E(Pol)_{Vendor\ Trips} + E(Pol)_{Off-Gasing}}$$

Equation 4-2

4.3.1 Fugitive Dust

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air during **demolition, site grading, trenching, and excavation** operations. Dust generated from these sources is termed “fugitive” because it is not discharged to the atmosphere in a confined flow stream. The dust-generation process is caused by two basic physical phenomena:

1. Pulverization and abrasion of surface materials by application of mechanical force through implements (wheels, blades, etc.)
2. Entrainment of dust particles by the action of turbulent air currents, such as wind erosion of an exposed surface by wind speeds over 12 miles per hour (mph).

4.3.1.1 Demolition Fugitive Dust Emissions

Fugitive dust emissions from the demolition phase of construction are a function of the volume being demolished. The volume is calculated by taking the product of the building area and its height. Fugitive dust emissions may be estimated by applying an EF to the area and height as shown:

$$E(PM_{10}) = 0.00042 \times BA \times BH$$

Equation 4-3

Where,

$E(PM_{10})$= PM_{10} emissions (lb)
0.00042 = Emission factor (lb/ft^3)
BA = Area of building to be demolished (ft^2)
BH = Height of building to be demolished (ft)

This equation is based on Table A9-9-H of the South Coast Air Quality Management District's (SCAQMD) California Environmental Quality Act Air Quality Handbook (SCAQMD 2007).

4.3.1.2 Site Grading, Excavation and Trenching Fugitive Dust Emissions

The fugitive dust emissions may be estimated using the methodology developed for SCAQMD by the Midwest Research Institute. The following equation is used to estimate daily PM_{10} generated by site grading, excavation, and trenching using the default EF of 20 lb/acre-day (0.22 tons/acre-month at 22 days/month):

$$E(PM_{10}) = 20 \times GA \times WD$$

Equation 4-4

Where,

20 = Factor converting acre-day to lb (lb/acre-day)
GA = Grading area (acre). **Note that, as a rule, the grading area should be about twice the size of the building being constructed.**
WD = Work duration, estimated in workdays (days). **Note that this is workdays, not total duration days.**

4.3.2 Construction Exhaust (Off-Road Equipment) Emissions

Emissions are generated by the operation of off-road construction equipment, such as concrete saws and bulldozers. Emissions from off-road equipment are estimated using the total operating time of the equipment and the appropriate EF. The operating time is estimated using the per day average use in hours of each equipment type. Typical operating times for different types of equipment may be either estimated or taken from CALEEMOD and URBEMIS. Criteria Pollutant and GHG emissions from each off-road engine may be calculated using the EFs, based on construction year, provided in Table 4-3 through Table 4-14. Additionally default horse-powers and load factors for various pieces of off-road equipment can be found in Table 4-15. Emissions are calculated as follows:

$$E(Pol) = \sum_{i=1}^{n} [WD \times EF(Pol)_i \times H \times N_i \times \mathbf{hp} \times \mathbf{LF} \times 0.002205]$$

Equation 4-5

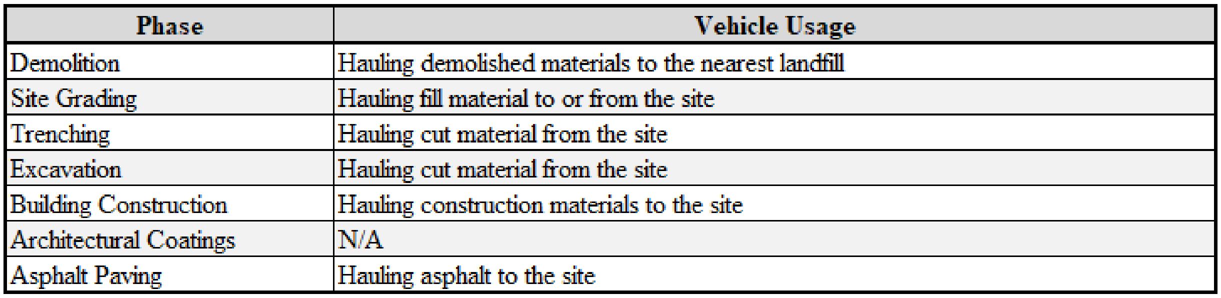
Where,

E(Pol) = Emissions of individual pollutant for all equipment types (lb)
WD = Work duration (days)
EF(Pol)$_i$ = Emission factor for specific equipment (g/hp-hr)
H = Hours worked per day (hr/day)
N$_i$ = Number of specific pieces of equipment
hp = horsepower of offroad equipment (hp)
LF = Load Factor of off-road equipment (unitless)
i = Denotes the individual equipment types
0.002205 = Factor for converting grams to pounds (lb/g)

4.3.3 Vehicle Exhaust (On-Road) Emissions

The following table provides a summary of the on-road vehicle usage for each construction phase:

Table 4-2. On-Road Vehicle Usage for Construction



Phase	Vehicle Usage
Demolition	Hauling demolished materials to the nearest landfill
Site Grading	Hauling fill material to or from the site
Trenching	Hauling cut material from the site
Excavation	Hauling cut material from the site
Building Construction	Hauling construction materials to the site
Architectural Coatings	N/A
Asphalt Paving	Hauling asphalt to the site

The calculation of on-road vehicle exhaust emissions is the same for all construction phases:

$$E(Pol)_{Total} = VMT_{Total} \times EF(Pol)_{Total} \times 0.002205$$

Equation 4-6

Where,

E(Pol)$_{Total}$ = Total annual emissions of specific pollutant from vehicle exhaust (lb/yr)
VMT$_{Total}$ = Total vehicle miles traveled (miles/year)
EF(Pol)$_{Total}$ = Total annual emissions of specific pollutant from vehicle exhaust (lb/yr)
0.002205 = Factor for converting grams to pounds (lb/g)

$$\boldsymbol{EF(Pol)_{Total} = \sum_{i=1}^{n} \left\{ \left(\frac{MIX_i}{100} \right) \times EF(Pol)_i \times \left[1 - \frac{FERF(Pol)}{100} \right] \right\}}$$

Equation 4-7

Where,

MIXi = Vehicle mix for a specific vehicle category (%). Note that this will vary across construction phases.

FERF(Pol) = Pollutant-specific Fuel Emission Reduction Factor, as applicable (%). Typically, this is assumed to be 0, but values are provided in the appropriate section of the latest version of the *Air Emissions Guide for Air Force Mobile Sources*

i = Vehicle category identifier (1 = LDGV, 2 = LDDV, etc.)

The challenge in estimating emissions using Equation 4-6 is that the VMT may be difficult to estimate. The recommended approach to estimating the VMT is to take the product of the total round trips made and the average miles per trip as shown:

$$\boldsymbol{VMT = Round\ Trips \times HT}$$

Equation 4-8

Where,

HT = Average hauling truck round trip commute (miles/trip). **Assume 20 miles/trip if unknown.**

The number of round trips made can now be estimated based on the construction phase. The procedures for determining the number of trips are outlined in the following sections.

4.3.3.1 Demolition Round Trips

The number of round trips taken by each vehicle during the demolition phase may be estimated using the demolition volume (product of the building height and area). By using the demolition volume, the average truck hauling capacity, and applying a volume reduction factor, the number of round trips is calculated as follows:

$$\boldsymbol{Round\ Trips = BA \times BH \times \frac{1}{27} \times 0.25 \times \frac{1}{HC}}$$

Equation 4-9

Where,

BA = Area of building to be demolished (ft^2)

BH = Height of building to be demolished (ft)

27 = Factor converting ft^3 to yd^3 (yd^3/ft^3)

0.25 = Volume reduction factor (material reduced by 75% to account for air space)

HC = Average truck hauling capacity per trip (yd^3/trip). Assume 20 yd^3/trip if unknown.

4.3.3.2 Site Grading (Fill) or Trenching (Cut) Round Trips

To estimate the number of round trips made during the site grading and trenching phase of construction, the amount of fill material (Fill) to be hauled to the site and the amount of cut material (Cut) to be hauled away from the site must be accounted for. The number of round trips may be estimated as shown:

$$\boldsymbol{Round\ Trips_{Fill} = FILL \times \frac{1}{HC}}$$

Equation 4-10

$$\boldsymbol{Round\ Trips_{Cut} = CUT \times \frac{1}{HC}}$$

Equation 4-11

Where,

FILL = Amount of fill material hauled to the site (ft^3)
CUT = Amount of cut material hauled away from the site (ft^3)
HC = Average truck hauling capacity per trip (yd^3/trip). **Assume 20 yd^3/trip if unknown.**

4.3.3.3 Building Construction Material Round Trips

Based on guidance provided by CALEEMOD and URBEMIS, the round trips made during building construction are grouped into different general land use categories and estimated as follows:

Military Family Housing:

$$\boldsymbol{Round\ Trips_{Multifamily} = N \times 0.36}$$

Equation 4-12

$$\boldsymbol{Round\ Trips_{Single-Family} = N \times 0.72}$$

Equation 4-13

Base Exchange, Commissary, etc.:

$$\boldsymbol{Round\ Trips_{Commercial\ or\ Retail} = CA \times \frac{1}{1000} \times 0.32}$$

Equation 4-14

Offices or Industrial Buildings:

$$\boldsymbol{Round\ Trips_{Office\ or\ Industrial} = CA \times \frac{1}{1000} \times 0.42}$$

Equation 4-15

Where,

N = Number of units
0.36/0.72 = Factor converting units to trips (trips/unit)
CA = Construction area (ft^2)
1000 = Factor converting ft^2 to 10^3 ft^2 (10^3 ft^2/ft^2)
0.32/0.42 = Factor converting 10^3 ft to trips (trips/10^3 ft^2)

4.3.3.4 Paving Round Trips

Estimating the number of round trips made during paving operations is a function of the volume of pavement applied to the surface. The volume used in this calculation is the product of the area paved and pavement thickness, which is assumed to be 0.25 ft. The number of round trips made during paving operations is calculated as shown:

$$\boldsymbol{Round\ Trips_{Paving} = PA \times 0.25 \times \frac{1}{27} \times \frac{1}{HC}}$$

Equation 4-16

Where,

PA = Paving area (ft^2)
0.25 = Thickness of paved area (ft)
27 = Factor converting ft^3 to yd^3 (yd^3/ft^3)
HC = Average truck hauling capacity per trip (yd^3/trip). **Assume 20 yd^3/trip if unknown.**

4.3.4 Worker Commute Trip Emissions

Emissions are generated by the operation of on-road private vehicles to and from the site. As with vehicle exhaust emissions, the emissions from workers commuting may be estimated using Equation 4-6 but **assumes a vehicle mix (MIX_i) of 50% LDGV and 50% LDGT.** The method for estimating VMT from workers commuting is different than the method provided for estimating VMT from vehicle exhaust. The VMT estimating methods for each construction phase are provided below.

4.3.4.1 VMT Estimates for Construction Phases Excluding Architectural Coatings

The process of estimating VMT for demolition, site grading, trenching, excavating, building construction, and paving is the same. The recommended method for estimating VMT for workers commuting is to first assume that the total number of workers is equal to 125% of the total pieces of construction equipment selected for each phase. Based on the number of total pieces of equipment in use (N_i) in each phase and applying the total workdays, an estimate of VMT is possible:

$$\boldsymbol{VMT = 1 \times WD \times WT \times 1.25 \times \sum_{i=1}^{n} N_i}$$

Equation 4-17

Where,

1 = Number of worker trips per day (trip/day)
WD = Work duration (days)
WT = Average worker round trip commute (miles/trip). Assume 20 miles/trip if unknown.
1.25 = Factor converting the number of construction equipment to the number of workers
N_i = Number of total pieces of construction equipment in use

4.3.4.2 VMT Estimates for Architectural Coating

Worker commute trips associated with architectural coating are assumed to equal the number of single-day trips one worker, that operates at a rate of 800 ft^2/day, would need to commute to complete painting the area to be coated:

$$\boldsymbol{VMT_{Arch.Painting} = \frac{(1 \times WT \times SA)}{800}}$$

Equation 4-18

Where,

1 = Number of worker trips per day (trip/day)
WT = Average worker round trip commute (miles/trip). **Assume 20 miles/trip if unknown.**
SA = Area of surface to be coated (ft^2)
800 = Assumed worker rate of paint application (ft^2/day)

4.3.5 Vendor Trip Emissions

Vendor trips represent the on-road vehicle trips needed to bring building supplies to the worksite **during the Building Construction phase only.** Vendor trip emissions are calculated using Equation 4-8 and the **assumption that the hauling truck commute is about 40 miles per trip, if unknown.**

Vendor trips are calculated using information provided by the Sacramento Metropolitan Air Quality Management District:

Military Family Housing:

$$\boldsymbol{Round\ Trips_{Multifamily/Single-Family} = N \times 0.11}$$

Equation 4-19

Base Exchange or Commissary:

$$\boldsymbol{Round\ Trips_{Commercial\ or\ Retail} = CA \times \frac{1}{1000} \times 0.05}$$

Equation 4-20

Offices or Industrial Buildings:

$$\boldsymbol{Round\ Trips_{Office\ or\ Industrial} = CA \times \frac{1}{1000} \times 0.38}$$

Equation 4-21

Where,

N = Number of units
CA = Construction area (ft^2)
0.11/0.05/0.38 = Factor converting units to trips (trip/unit)

Finally, emissions from vendor trips are calculated using Equation 4-6 assuming the vehicle mix is 100% Heavy-Duty Diesel Vehicles (HDDV).

4.3.6 Off-Gassing Emissions

Off-Gassing occurs **during the Architectural Coatings and Paving phases** due to evaporation of solvents contained in surface coatings and asphalt. Emissions from these phases are calculated differently and described below.

4.3.6.1 Architectural Coatings

Separate procedures are used to estimate evaporative emissions from application of residential and non-residential architectural coatings. Emissions are based on the total surface area to be coated (ft^2), the coating coverage (ft^2/gal), and VOC content (g/L) of the coating.

Surface Area Size

The surface area to be painted (SA) is estimated using the following equations:

Military Family Housing:

$$\boldsymbol{SA_{Multifamily} = N \times 850 \times 2.7}$$

Equation 4-22

$$SA_{Single-Family} = N \times 1800 \times 2.7$$

Equation 4-23

Where,

N = Number of units
850 = Factor converting units to square feet (ft^2/units)
1800 = Factor converting units to square feet (ft^2/units)
2.7 = Factor converting total area to coated area

All Other Buildings:

$$SA_{Non-Residential} = \sqrt{BA} \times 4 \times BH$$

Equation 4-24

Where,

BA = Total building square footage (ft^2)
BH = Building height (ft)
4 = Number of walls, assuming a square shaped building

This equation assumes the length and width of the building are equal. If the total building square footage is unknown, this value can be calculated by multiplying the length of the building by the width of the building.

Emission Factor:

For architectural coatings, California has calculated a statewide average VOC content of 250 grams VOC per liter of paint. Per CALEEMOD 2022, an average coating coverage of 180 square feet per gallon is assumed. A VOC EF may be derived as shown:

$$EF(VOC) = SA \times \frac{250\ \cancel{g\ VOCs}}{1\ \cancel{L\ Paint}} \times \frac{1\ \cancel{gal\ Paint}}{180\ ft^2} \times \frac{1\ lb}{454\ \cancel{g}} \times \frac{3.785\ \cancel{L}}{1\ \cancel{gal}} = 0.0116\frac{lb}{ft^2}$$

Emissions Estimate:

Using the surface area and EF derived above, the total VOC emissions can be estimated as follows:

$$E(VOC) = SA \times 0.0116$$

Equation 4-25

4.3.6.2 Paving (Asphalt)

VOC emissions are estimated by multiplying the area to be paved by the asphalt EF of 2.62 pounds per acre (Sacramento Metropolitan Air Quality Management District 1994). VOC emissions are estimated using the following formula:

$$\boldsymbol{E(VOC) = \frac{PA \times 2.62}{43,560}}$$

Equation 4-26

Where,

PA = Paving area (ft^2)
2.62 = Emission factor (lb/acre)
43,560 = Factor converting square feet to acres (ft^2/acre)

4.4 Information Resources

Construction operations may be performed either by Civil Engineering or by a contracted company. Base Civil Engineering should be able to provide information needed to estimate emissions and should be contacted for all pertinent data. Emissions may be estimated through several software programs such as ACAM. Refer to the supporting documentation for these programs for assumptions made and guidance in estimating emissions.

4.5 Example Problem

During calendar year 2020, a DAF Base (located in Alabama – 600 feet above sea level) contracted a company to demolish an existing building. The building was described as 5,000 square feet and 18 feet tall on a one-acre lot. The demolition took 4 weeks to complete with a typical 8-hr, 5-day work week. The contractor stated that during demolition, two 120 horsepower (hp) tractors, one 250 hp rubber tire dozer, and two 50 hp concrete saws were used. The contractor's best estimate was that the tractors, dozer, and saws operated for 6, 4, and 5 hours per day on average. Calculate the PM_{10} emissions from the demolition of this building.

<u>Step 1</u> – **Determine the emission classes associated with demolition.** Looking at Table 4-1, the classes associated with demolition include: **fugitive dust, construction exhaust, vehicle exhaust, and worker trips.**

<u>Step 2</u> – **Calculate fugitive dust emissions.** Using the building area, height, and Equation 4-3, PM_{10} emissions are calculated as shown:

$$E(PM_{10}) = 0.00042 \times BA \times BH$$

$$E(PM_{10})_{Fugitive\ Dust} = 0.00042 \frac{lb}{ft^3} \times 5000\ ft^2 \times 18\ ft$$

$$\boldsymbol{E(PM_{10})_{Fugitive\ Dust}} = 0.00042 \frac{lb}{\cancel{ft^3}} \times 90000\ \cancel{ft^3} = \mathbf{37.8\ lb}$$

Step 3 – **Calculate the workdays.** The problem stated that the process took four 5-day work weeks to complete. The number of workdays is estimated as follows:

$$\boldsymbol{WD} = 28\ \cancel{days} \times \frac{5\ days}{7\ \cancel{days}} = \mathbf{20\ days}$$

Step 4 – **Select and record the appropriate EFs.** Construction equipment EFs for 220 are provided in Table 4-3. The PM_{10} EFs for the tractor, dozer, and saw are **0.203, 0.201, and 0.137 g/hp-hr**, respectively.

Step 5 – **Calculate construction exhaust emissions.** Using the EFs provided in Step 4, the workdays estimated in Step 3, the data in the problem statement, and Equation 4-5, the emissions from construction exhaust are calculated as follows:

$$\boldsymbol{E(Pol)} = \sum_{\boldsymbol{i=1}}^{\boldsymbol{n}} [WD \times EF(Pol)_i \times H \times N_i \times \text{hp} \times \text{LF}]$$

$$E(PM_{10})_{Construction\ Exhaust}$$
$$= \Bigg[\left(20\ \cancel{days} \times 0.203 \frac{g}{\cancel{hp-hr}} \times 6 \frac{\cancel{hr}}{\cancel{day}} \times 2 \times 38\ \cancel{hp} \times .44\right) + \left(20\ \cancel{days} \times 0.201 \frac{g}{\cancel{hp-hr}} \times 4 \frac{\cancel{hr}}{\cancel{day}} \times 1 \times 367\ \cancel{hp} \times .40\right) + \left(20\ \cancel{days} \times 0.137 \frac{g}{\cancel{hp-hr}} \times 5 \frac{\cancel{hr}}{\cancel{day}} \times 2 \times 33\ \cancel{hp} \times .73\right)\Bigg]$$

$$\boldsymbol{E(PM_{10})_{Construction\ Exhaust}} = [(1851.4\ g) + (4{,}721.1\ g) + (660.1\ g)] = \mathbf{3{,}835.21\ g}$$

$$\boldsymbol{E(PM_{10})_{Construction\ Exhaust}} = 3{,}835.21\ \text{g} \times\ 0.002205\ \frac{lb}{\cancel{g}} = \mathbf{8.46\ lb}$$

Step 6 – **Calculate the number of round trips made that contributed to vehicle exhaust.** The demolition phase of construction also results in vehicle exhaust emissions that must be calculated. The first step in making this calculation is to determine the number of round trips made. Using the area and height of the demolished building and assuming the truck hauling capacity is 20 yd^3/trip, an estimate of the number of round trips may be calculated using Equation 4-9:

$$Round\ Trips = BA \times BH \times \frac{1}{27} \times 0.25 \times \frac{1}{HC}$$

$$Round\ Trips = 5000\ ft^2 \times 18\ ft \times \frac{1}{27}\frac{yd^3}{ft^3} \times 0.25 \times \frac{1}{20}\frac{trip}{yd^3}$$

$$Round\ Trips = 90000\ \cancel{ft^3} \times \frac{1}{27}\frac{yd^3}{\cancel{ft^3}} \times 0.25 \times \frac{1}{20}\frac{trip}{yd^3}$$

$$Round\ Trips = 3333.33\ \cancel{yd^3} \times 0.25 \times \frac{1}{20}\frac{trip}{\cancel{yd^3}}$$

$$\boldsymbol{Round\ Trips} = 166.67\ \text{trip} \times 0.25 = \mathbf{42\ trips}$$

<u>Step 7</u> – Calculate the VMT. Using the number of round trips made as estimated by Step 6 and assuming the average hauling truck commute is 20 miles/trip, the VMT may be calculated using Equation 4-8:

$$VMT = Round\ Trips \times HT$$

$$\boldsymbol{VMT} = 42\ \cancel{trips} \times 20\ \frac{miles}{\cancel{trip}} = 840\ miles$$

<u>Step 8</u> – Select and record the appropriate EF. The vehicle mix for vehicle exhaust emissions is assumed to be 100% HDDV. For CY2023, the PM_{10} EF in Alabama, according to the 2023 *Air Emissions Guide for Air Force Mobile Sources*, is **0.007 g/mile**.

<u>Step 9</u> – Calculate vehicle exhaust emissions. Using the EF recorded in Step 8, the VMT calculated in Step 7, and Equation 4-6, the PM_{10} emissions from vehicle exhaust is calculated as follows:

$$E(Pol) = VMT \times EF(Pol) \times 0.002205$$

$$E(PM_{10})_{Vehicle\ Emissions} = 840\ \cancel{\text{miles}} \times 0.007\ \frac{g}{\cancel{mile}} \times 0.002205\ \frac{lb}{\cancel{g}}$$

$$\boldsymbol{E(PM_{10})_{Vehicle\ emissions}} = \mathbf{0.013\ lb}$$

<u>Step 10</u> – Estimate the VMT for worker commute. Assuming an average worker commute of 20 miles/trip, the workdays estimated in Step 3, and Equation 4-17, the VMT is calculated as follows:

$$VMT = 1 \times WD \times WT \times 1.25 \times \sum_{i=1}^{n} N_i$$

$$\boldsymbol{VMT} = 1\frac{\cancel{trip}}{\cancel{day}} \times 20\ \cancel{days} \times 20\ \frac{miles}{\cancel{trip}} \times 1.25 \times 4 = \mathbf{2,000\ miles}$$

<u>Step 11</u> – Select and record the appropriate EFs. Assuming a mix of LDGV and LDGT for worker vehicle types, the EFs for PM_{10} from the 2023 *Air Emissions Guide for Air Force Mobile Sources* are **0.004 and 0.005 g/miles, respectively**.

<u>Step 12</u> – Calculate the composite EF. Assuming a vehicle mix of 50% LDGV and 50% LDGT, a FERF of 0, and the EFs recorded in Step 11, the composite EF is calculated using Equation 4-7 as follows:

$$EF(Pol)_{Total} = \sum_{i=1}^{n}\left\{\left(\frac{MIX_i}{100}\right) \times EF(Pol)_i \times \left[1 - \frac{FERF(Pol)}{100}\right]\right\}$$

$$EF(PM_{10}) = \sum\left\{\left(\frac{50\cancel{\%}}{100\cancel{\%}}\right) \times 0.004\ \frac{g}{mile} \times \left[\cancel{1 - \frac{0\%}{100\%}}\right]\right\} + \left\{\left(\frac{50\cancel{\%}}{100\cancel{\%}}\right) \times 0.005\ \frac{g}{mile} \times \left[\cancel{1 - \frac{0\%}{100\%}}\right]\right\}$$

$$\boldsymbol{EF(PM_{10})} = \sum\left\{0.5 \times 0.004\ \frac{g}{mile}\right\} + \left\{0.5 \times 0.005\ \frac{g}{mile}\right\} = \mathbf{0.0045}\ \boldsymbol{\frac{g}{mile}}$$

<u>Step 13</u> – Calculate emissions from worker trips. Using Equation 4-6, the VMT calculated in Step 10, and the EF calculated in Step 12, the PM_{10} emissions are calculated as follows:

$$E(Pol)_{Total} = VMT_{Total} \times EF(Pol)_{Total} \times 0.002205$$

$$\boldsymbol{E(PM_{10})_{Worker\ Trips}} = 2000\ \cancel{\text{miles}} \times 0.0045\ \frac{\cancel{g}}{\cancel{mile}} \times 0.002205\frac{lb}{\cancel{g}} = \mathbf{0.01764}\ \boldsymbol{lb}$$

<u>Step 14</u> – Calculate total PM_{10}. The final step is to sum the PM_{10} emissions from each class comprising the demolition phase of construction using Equation 4-2:

$$E(Pol)_i = E(Pol)_{Fugitive\ Dust} + E(Pol)_{Construction\ Exhaust} + E(Pol)_{Vehicle\ Emissions} + E(Pol)_{Worker\ Trips} + E(Pol)_{Vendor\ Trips} + E(Pol)_{Off-Gasing}$$

$$E(PM_{10})_{Demolition} = 37.8\text{ lb} + 12.16\text{ lb} + 0.307\ lb + 0.0309\text{ lb} + 0 + 0$$

$$\boxed{\boldsymbol{E(PM_{10})_{Demolition}} = \mathbf{46.3\ lb}}$$

Table 4-3. Criteria Pollutant Emission Factors for Off-Road Equipment - 2023

Equipment	Emission Factor (g/hp-hr)					
	NO_X	CO	SO_X	VOC	PM_{10}	$PM_{2.5}$
Aerial Lifts	2.895	3.120	0.005	0.162	0.023	0.021
Air Compressors	3.976	4.914	0.007	0.623	0.157	0.144
Bore/Drill Rigs	2.068	3.296	0.005	0.178	0.083	0.077
Cement and Mortar Mixers	4.206	3.259	0.009	0.555	0.165	0.151
Concrete/Industrial Saws	3.862	4.426	0.007	0.507	0.137	0.126
Cranes	2.232	1.703	0.005	0.213	0.089	0.082
Crawler Tractors	4.682	3.852	0.005	0.548	0.367	0.338
Crushing/Proc. Equipment	4.732	267.506	0.012	188.517	3.266	2.468
Dumpers/Tenders	4.366	2.358	0.007	0.571	0.163	0.150
Excavators	3.587	4.226	0.005	0.448	0.139	0.128
Forklifts	2.981	3.630	0.005	0.316	0.182	0.168
Generator Sets	4.402	2.894	0.008	0.550	0.184	0.170
Graders	3.506	3.420	0.005	0.385	0.193	0.177
Off-Highway Tractors	3.991	4.842	0.005	0.656	0.203	0.187
Off-Highway Trucks	1.325	1.211	0.005	0.186	0.048	0.044
Other Construction Equipment	3.539	3.587	0.005	0.381	0.240	0.221
Other General Industrial Equipment	3.989	4.877	0.005	0.601	0.194	0.178
Other Material Handling Equipment	2.047	3.449	0.005	0.188	0.080	0.074
Pavers	2.711	3.396	0.005	0.233	0.137	0.126
Paving Equipment	2.584	3.452	0.005	0.247	0.129	0.119
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.450	3.287	0.009	0.538	0.189	0.174
Pumps	4.398	3.025	0.008	0.588	0.191	0.176
Rollers	3.911	4.241	0.005	0.659	0.211	0.194
Rough Terrain Forklifts	1.836	3.217	0.005	0.125	0.045	0.041
Rubber Tired Dozers	4.462	3.582	0.005	0.445	0.201	0.185
Rubber Tired Loaders	2.211	3.295	0.005	0.271	0.119	0.109
Scrapers	2.474	1.761	0.005	0.237	0.095	0.087
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	2.031	3.260	0.005	0.153	0.069	0.063
Surfacing Equipment	1.214	1.067	0.005	0.114	0.046	0.043
Sweepers/Scrubbers	4.124	4.967	0.005	0.759	0.248	0.228
Tractors/Loaders/Backhoes	2.317	3.487	0.005	0.225	0.111	0.102
Trenchers	3.949	4.291	0.005	0.640	0.219	0.202
Welders	3.891	4.596	0.007	0.577	0.151	0.139

Notes for Table 4-3 through Table 4-8 are located under Table 4-8.

Table 4-4. Criteria Pollutant Emission actors for Off-Road Equipment – 2024

Equipment	Emission Factor (g/hp-hr)					
	NO$_X$	CO	SO$_X$	VOC[a]	PM$_{10}$	PM$_{2.5}$
Aerial Lifts	2.886	3.111	0.005	0.158	0.022	0.020
Air Compressors	3.865	4.881	0.007	0.581	0.136	0.125
Bore/Drill Rigs	1.952	3.277	0.005	0.165	0.072	0.067
Cement and Mortar Mixers	4.202	3.257	0.009	0.554	0.164	0.151
Concrete/Industrial Saws	3.744	4.381	0.007	0.470	0.117	0.108
Cranes	2.131	1.680	0.005	0.210	0.086	0.079
Crawler Tractors	4.305	3.807	0.005	0.500	0.328	0.301
Crushing/Proc. Equipment	4.724	267.629	0.012	188.507	3.267	2.469
Dumpers/Tenders	4.368	2.359	0.007	0.571	0.163	0.150
Excavators	3.501	4.197	0.005	0.415	0.119	0.110
Forklifts	2.751	3.615	0.005	0.292	0.157	0.145
Generator Sets	4.373	2.881	0.008	0.546	0.180	0.166
Graders	3.176	3.405	0.005	0.361	0.175	0.161
Off-Highway Tractors	3.853	4.749	0.005	0.594	0.174	0.160
Off-Highway Trucks	1.236	1.195	0.005	0.183	0.044	0.041
Other Construction Equipment	3.241	3.563	0.005	0.343	0.209	0.192
Other General Industrial Equipment	3.856	4.776	0.005	0.545	0.165	0.152
Other Material Handling Equipment	1.983	3.425	0.005	0.181	0.074	0.068
Pavers	2.708	3.423	0.005	0.248	0.144	0.133
Paving Equipment	2.410	3.447	0.005	0.226	0.109	0.100
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.414	3.275	0.009	0.534	0.184	0.169
Pumps	4.365	3.012	0.008	0.581	0.185	0.170
Rollers	3.814	4.195	0.005	0.618	0.192	0.177
Rough Terrain Forklifts	1.794	3.224	0.005	0.125	0.043	0.040
Rubber Tired Dozers	4.010	3.253	0.005	0.409	0.179	0.164
Rubber Tired Loaders	1.902	3.293	0.005	0.248	0.102	0.094
Scrapers	2.292	1.711	0.005	0.229	0.089	0.081
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.918	3.255	0.005	0.142	0.059	0.054
Surfacing Equipment	1.236	1.071	0.005	0.117	0.046	0.043
Sweepers/Scrubbers	4.075	4.998	0.005	0.745	0.238	0.219
Tractors/Loaders/Backhoes	2.192	3.495	0.005	0.215	0.097	0.089
Trenchers	3.824	4.222	0.005	0.599	0.196	0.180
Welders	3.783	4.558	0.007	0.534	0.131	0.120

Notes for Table 4-3 through Table 4-8 are located under Table 4-8.

Table 4-5. Criteria Pollutant Emission Factors for Off-Road Equipment - 2025

Equipment	Emission Factor (g/hp-hr)					
	NO_X	CO	SO_X	VOC[a]	PM_{10}	$PM_{2.5}$
Aerial Lifts	2.88	3.09	0.01	0.15	0.02	0.02
Air Compressors	3.76	4.85	0.01	0.54	0.12	0.11
Bore/Drill Rigs	1.74	3.25	0.00	0.14	0.05	0.05
Cement and Mortar Mixers	4.20	3.26	0.01	0.55	0.16	0.15
Concrete/Industrial Saws	3.63	4.35	0.01	0.44	0.10	0.09
Cranes	1.95	1.66	0.00	0.20	0.08	0.07
Crawler Tractors	3.88	3.75	0.00	0.44	0.28	0.26
Crushing/Proc. Equipment	4.73	267.50	0.01	188.50	3.27	2.47
Dumpers/Tenders	4.37	2.36	0.01	0.57	0.16	0.15
Excavators	3.45	4.21	0.01	0.40	0.11	0.10
Forklifts	2.55	3.60	0.00	0.27	0.13	0.12
Generator Sets	4.35	2.87	0.01	0.54	0.18	0.16
Graders	2.86	3.42	0.00	0.34	0.16	0.15
Off-Highway Tractors	3.68	4.61	0.01	0.52	0.14	0.13
Off-Highway Trucks	1.09	1.17	0.00	0.18	0.04	0.04
Other Construction Equipment	2.89	3.51	0.00	0.30	0.17	0.16
Other General Industrial Equipment	3.71	4.67	0.01	0.49	0.14	0.13
Other Material Handling Equipment	1.96	3.46	0.00	0.18	0.07	0.06
Pavers	2.65	3.45	0.00	0.25	0.14	0.13
Paving Equipment	2.22	3.42	0.00	0.20	0.09	0.08
Plate Compactors	4.14	3.47	0.01	0.55	0.16	0.15
Pressure Washers	4.38	3.26	0.01	0.53	0.18	0.17
Pumps	4.33	3.00	0.01	0.57	0.18	0.17
Rollers	3.68	4.11	0.01	0.57	0.17	0.15
Rough Terrain Forklifts	1.69	3.22	0.00	0.12	0.04	0.03
Rubber Tired Dozers	3.51	2.90	0.00	0.37	0.15	0.14
Rubber Tired Loaders	1.60	3.28	0.00	0.23	0.08	0.08
Scrapers	1.91	1.58	0.00	0.20	0.07	0.07
Signal Boards	4.14	3.47	0.01	0.55	0.16	0.15
Skid Steer Loaders	1.86	3.25	0.00	0.14	0.06	0.05
Surfacing Equipment	0.99	1.07	0.00	0.11	0.04	0.03
Sweepers/Scrubbers	3.85	4.76	0.01	0.62	0.19	0.18
Tractors/Loaders/Backhoes	2.01	3.48	0.00	0.20	0.08	0.07
Trenchers	3.65	4.11	0.01	0.54	0.16	0.15
Welders	3.68	4.52	0.01	0.50	0.11	0.10

Notes for Table 4-3 through Table 4-8 are located under Table 4-8.

Table 4-6. Criteria Pollutant Emission Factors for Off-Road Equipment - 2026

Equipment	Emission Factor (g/hp-hr)					
	NO_X	CO	SO_X	VOC[a]	PM_{10}	$PM_{2.5}$
Aerial Lifts	2.874	3.075	0.005	0.152	0.021	0.019
Air Compressors	3.646	4.822	0.007	0.512	0.099	0.091
Bore/Drill Rigs	1.639	3.253	0.005	0.128	0.040	0.037
Cement and Mortar Mixers	4.198	3.255	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.526	4.315	0.007	0.413	0.085	0.078
Cranes	1.837	1.637	0.005	0.198	0.075	0.069
Crawler Tractors	3.631	3.725	0.005	0.414	0.251	0.231
Crushing/Proc. Equipment	4.725	267.313	0.012	188.498	3.263	2.465
Dumpers/Tenders	4.358	2.354	0.007	0.570	0.163	0.150
Excavators	3.407	4.221	0.005	0.393	0.099	0.091
Forklifts	2.342	3.579	0.005	0.246	0.112	0.103
Generator Sets	4.324	2.860	0.008	0.539	0.174	0.160
Graders	2.528	3.397	0.005	0.313	0.140	0.129
Off-Highway Tractors	3.617	4.600	0.005	0.490	0.126	0.116
Off-Highway Trucks	1.011	1.178	0.005	0.176	0.036	0.033
Other Construction Equipment	2.734	3.504	0.005	0.282	0.158	0.145
Other General Industrial Equipment	3.588	4.594	0.005	0.453	0.113	0.104
Other Material Handling Equipment	1.906	3.450	0.005	0.177	0.060	0.055
Pavers	2.533	3.431	0.005	0.237	0.129	0.119
Paving Equipment	2.065	3.403	0.005	0.190	0.080	0.074
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.349	3.253	0.009	0.526	0.178	0.163
Pumps	4.309	2.993	0.008	0.569	0.177	0.163
Rollers	3.614	4.093	0.005	0.542	0.154	0.142
Rough Terrain Forklifts	1.643	3.220	0.005	0.115	0.033	0.030
Rubber Tired Dozers	3.223	2.726	0.005	0.353	0.142	0.131
Rubber Tired Loaders	1.398	3.293	0.005	0.211	0.073	0.067
Scrapers	1.741	1.539	0.005	0.196	0.068	0.062
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.807	3.245	0.005	0.134	0.051	0.047
Surfacing Equipment	0.834	1.053	0.005	0.096	0.030	0.027
Sweepers/Scrubbers	3.759	4.731	0.005	0.584	0.171	0.157
Tractors/Loaders/Backhoes	1.885	3.481	0.005	0.184	0.063	0.058
Trenchers	3.536	4.047	0.005	0.506	0.141	0.130
Welders	3.570	4.493	0.007	0.465	0.095	0.088

Notes for Table 4-3 through Table 4-8 are located under Table 4-8.

Table 4-7. Criteria Pollutant Emission Factors for Off-Road Equipment - 2027

Equipment	Emission Factor (g/hp-hr)					
	NO_X	CO	SO_X	VOC[a]	PM_{10}	$PM_{2.5}$
Aerial Lifts	2.870	3.070	0.005	0.151	0.020	0.019
Air Compressors	3.538	4.790	0.007	0.482	0.081	0.075
Bore/Drill Rigs	1.589	3.273	0.005	0.129	0.035	0.033
Cement and Mortar Mixers	4.198	3.255	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.430	4.291	0.007	0.390	0.071	0.065
Cranes	1.748	1.629	0.005	0.195	0.072	0.066
Crawler Tractors	3.310	3.690	0.005	0.372	0.215	0.198
Crushing/Proc. Equipment	4.722	267.383	0.012	188.489	3.263	2.465
Dumpers/Tenders	4.361	2.355	0.007	0.570	0.163	0.150
Excavators	3.367	4.216	0.005	0.378	0.089	0.082
Forklifts	2.152	3.568	0.005	0.228	0.092	0.085
Generator Sets	4.305	2.852	0.008	0.537	0.172	0.158
Graders	2.284	3.406	0.005	0.295	0.127	0.117
Off-Highway Tractors	3.536	4.569	0.005	0.453	0.107	0.098
Off-Highway Trucks	0.965	1.179	0.005	0.176	0.034	0.031
Other Construction Equipment	2.500	3.484	0.005	0.252	0.132	0.122
Other General Industrial Equipment	3.525	4.597	0.005	0.436	0.099	0.091
Other Material Handling Equipment	1.853	3.460	0.005	0.176	0.056	0.051
Pavers	2.450	3.438	0.005	0.229	0.119	0.110
Paving Equipment	2.016	3.403	0.005	0.183	0.075	0.069
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.331	3.250	0.009	0.524	0.175	0.161
Pumps	4.288	2.986	0.008	0.565	0.173	0.160
Rollers	3.577	4.105	0.005	0.529	0.146	0.134
Rough Terrain Forklifts	1.619	3.216	0.005	0.113	0.032	0.029
Rubber Tired Dozers	3.091	2.656	0.005	0.343	0.135	0.125
Rubber Tired Loaders	1.240	3.304	0.005	0.200	0.063	0.058
Scrapers	1.609	1.522	0.005	0.191	0.063	0.058
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.753	3.243	0.005	0.129	0.047	0.043
Surfacing Equipment	0.778	1.054	0.005	0.094	0.027	0.025
Sweepers/Scrubbers	3.671	4.690	0.005	0.541	0.149	0.137
Tractors/Loaders/Backhoes	1.807	3.487	0.005	0.177	0.054	0.050
Trenchers	3.445	3.992	0.005	0.467	0.122	0.112
Welders	3.466	4.461	0.007	0.435	0.079	0.073

Notes for Table 4-3 through Table 4-8 are located under Table 4-8.

Table 4-8. Criteria Pollutant Emission Factors for Off-Road Equipment - 2028

Equipment	Emission Factor (g/hp-hr)					
	NO_X	CO	SO_X	VOC[a]	PM_{10}	$PM_{2.5}$
Aerial Lifts	2.871	3.075	0.005	0.151	0.020	0.018
Air Compressors	3.440	4.760	0.007	0.457	0.065	0.060
Bore/Drill Rigs	1.597	3.288	0.005	0.132	0.035	0.033
Cement and Mortar Mixers	4.197	3.256	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.344	4.271	0.007	0.370	0.058	0.053
Cranes	1.601	1.628	0.005	0.187	0.066	0.061
Crawler Tractors	3.059	3.669	0.005	0.340	0.186	0.171
Crushing/Proc. Equipment	4.723	267.290	0.012	188.489	3.262	2.464
Dumpers/Tenders	4.362	2.356	0.007	0.571	0.163	0.150
Excavators	3.339	4.222	0.005	0.366	0.081	0.075
Forklifts	2.032	3.565	0.005	0.216	0.079	0.072
Generator Sets	4.289	2.846	0.008	0.535	0.170	0.156
Graders	2.086	3.418	0.005	0.281	0.116	0.106
Off-Highway Tractors	3.502	4.600	0.005	0.442	0.096	0.089
Off-Highway Trucks	0.889	1.170	0.005	0.174	0.032	0.029
Other Construction Equipment	2.433	3.486	0.005	0.245	0.124	0.114
Other General Industrial Equipment	3.447	4.548	0.005	0.409	0.084	0.077
Other Material Handling Equipment	1.789	3.479	0.005	0.174	0.050	0.046
Pavers	2.338	3.435	0.005	0.216	0.105	0.097
Paving Equipment	1.883	3.377	0.005	0.163	0.058	0.053
Plate Compactors	4.143	3.471	0.009	0.547	0.162	0.149
Pressure Washers	4.309	3.243	0.009	0.521	0.173	0.159
Pumps	4.270	2.980	0.008	0.561	0.171	0.157
Rollers	3.509	4.084	0.005	0.501	0.132	0.121
Rough Terrain Forklifts	1.576	3.208	0.005	0.109	0.029	0.027
Rubber Tired Dozers	3.041	2.663	0.005	0.342	0.134	0.123
Rubber Tired Loaders	1.098	3.317	0.005	0.191	0.054	0.050
Scrapers	1.493	1.500	0.005	0.185	0.059	0.054
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.712	3.245	0.005	0.126	0.043	0.039
Surfacing Equipment	0.699	1.057	0.005	0.091	0.025	0.023
Sweepers/Scrubbers	3.613	4.688	0.005	0.517	0.133	0.123
Tractors/Loaders/Backhoes	1.749	3.496	0.005	0.173	0.048	0.044
Trenchers	3.399	3.997	0.005	0.447	0.110	0.102
Welders	3.371	4.432	0.007	0.409	0.064	0.059

SOURCE (unless otherwise stated): California Air Resources Board, "OFFROAD2021". Source provided emission factors for aggregate model years and horsepower and were converted from tons per day to lb/hr using the provided activity. In instances where emission factors were provided for equipment which operate on both gasoline and diesel fuel, the emission factor with the larger population was selected.

a. Source provides emission factors for ROG which are assumed to be equal to VOC.

Table 4-9. GHG Emission Factors for Off-Road Equipment - 2023

Equipment	Emission Factor (g/hp-hr)			
	CO_2^{e}[a]	CH_4	N_2O	CO_2
Aerial Lifts	588.936	0.024	0.005	586.922
Air Compressors	570.276	0.023	0.005	568.326
Bore/Drill Rigs	525.117	0.021	0.004	523.321
Cement and Mortar Mixers	572.343	0.023	0.005	570.386
Concrete/Industrial Saws	577.273	0.023	0.005	575.299
Cranes	529.326	0.021	0.004	527.516
Crawler Tractors	530.723	0.021	0.004	528.908
Crushing/Proc. Equipment	434.447	0.018	0.004	432.907
Dumpers/Tenders	574.668	0.023	0.005	572.703
Excavators	588.896	0.024	0.005	586.882
Forklifts	528.905	0.021	0.004	527.097
Generator Sets	570.268	0.023	0.005	568.318
Graders	531.813	0.021	0.004	529.994
Off-Highway Tractors	587.708	0.024	0.005	585.698
Off-Highway Trucks	530.383	0.021	0.004	528.569
Other Construction Equipment	530.064	0.021	0.004	528.251
Other General Industrial Equipment	590.205	0.024	0.005	588.186
Other Material Handling Equipment	530.468	0.021	0.004	528.653
Pavers	527.588	0.021	0.004	525.783
Paving Equipment	530.544	0.021	0.004	528.729
Plate Compactors	570.301	0.023	0.005	568.351
Pressure Washers	580.528	0.023	0.005	578.543
Pumps	570.237	0.023	0.005	568.287
Rollers	588.845	0.024	0.005	586.831
Rough Terrain Forklifts	530.248	0.021	0.004	528.435
Rubber Tired Dozers	534.040	0.022	0.004	532.214
Rubber Tired Loaders	528.131	0.021	0.004	526.324
Scrapers	530.875	0.021	0.004	529.060
Signal Boards	570.250	0.023	0.005	568.299
Skid Steer Loaders	529.635	0.021	0.004	527.823
Surfacing Equipment	529.659	0.021	0.004	527.847
Sweepers/Scrubbers	589.193	0.024	0.005	587.177
Tractors/Loaders/Backhoes	531.565	0.021	0.004	529.747
Trenchers	590.099	0.024	0.005	588.081
Welders	570.242	0.023	0.005	568.291

Notes for Table 4-9 through 4-14 are located under Table 4-14.

Table 4-10. Greenhouse Gas Emission Factors for Off-Road Equipment - 2024

Equipment	Emission Factor (g/hp-hr)			
	CO_2e[a]	CH_4	N_2O	CO_2
Aerial Lifts	588.917	0.024	0.005	586.903
Air Compressors	570.311	0.023	0.005	568.361
Bore/Drill Rigs	523.223	0.021	0.004	521.434
Cement and Mortar Mixers	572.123	0.023	0.005	570.167
Concrete/Industrial Saws	576.878	0.023	0.005	574.905
Cranes	529.342	0.021	0.004	527.532
Crawler Tractors	530.528	0.021	0.004	528.713
Crushing/Proc. Equipment	434.593	0.018	0.004	433.053
Dumpers/Tenders	574.985	0.023	0.005	573.018
Excavators	589.332	0.024	0.005	587.317
Forklifts	528.848	0.021	0.004	527.040
Generator Sets	570.265	0.023	0.005	568.315
Graders	531.990	0.022	0.004	530.170
Off-Highway Tractors	587.573	0.024	0.005	585.564
Off-Highway Trucks	529.574	0.021	0.004	527.763
Other Construction Equipment	530.267	0.021	0.004	528.454
Other General Industrial Equipment	590.170	0.024	0.005	588.151
Other Material Handling Equipment	530.509	0.021	0.004	528.694
Pavers	528.138	0.021	0.004	526.332
Paving Equipment	529.927	0.021	0.004	528.115
Plate Compactors	570.303	0.023	0.005	568.353
Pressure Washers	580.459	0.023	0.005	578.474
Pumps	570.253	0.023	0.005	568.303
Rollers	588.812	0.024	0.005	586.798
Rough Terrain Forklifts	530.324	0.021	0.004	528.511
Rubber Tired Dozers	534.029	0.022	0.004	532.203
Rubber Tired Loaders	528.138	0.021	0.004	526.332
Scrapers	530.783	0.021	0.004	528.968
Signal Boards	570.254	0.023	0.005	568.303
Skid Steer Loaders	529.983	0.021	0.004	528.170
Surfacing Equipment	529.528	0.021	0.004	527.717
Sweepers/Scrubbers	589.022	0.024	0.005	587.008
Tractors/Loaders/Backhoes	531.752	0.021	0.004	529.933
Trenchers	589.921	0.024	0.005	587.904
Welders	570.240	0.023	0.005	568.290

Notes for Table 4-9 through 4-14 are located under Table 4-14.

Table 4-11. Greenhouse Gas Emission Factors for Off-Road Equipment - 2025

Equipment	Emission Factor (g/hp-hr)			
	CO_2^{e} [a]	CH_4	N_2O	CO_2
Aerial Lifts	588.914	0.024	0.005	586.900
Air Compressors	570.313	0.023	0.005	568.363
Bore/Drill Rigs	524.360	0.021	0.004	522.567
Cement and Mortar Mixers	572.132	0.023	0.005	570.175
Concrete/Industrial Saws	576.987	0.023	0.005	575.013
Cranes	529.395	0.021	0.004	527.585
Crawler Tractors	530.285	0.021	0.004	528.471
Crushing/Proc. Equipment	434.326	0.018	0.004	432.786
Dumpers/Tenders	574.846	0.023	0.005	572.880
Excavators	589.153	0.024	0.005	587.138
Forklifts	528.917	0.021	0.004	527.108
Generator Sets	570.273	0.023	0.005	568.322
Graders	533.017	0.022	0.004	531.194
Off-Highway Tractors	588.164	0.024	0.005	586.153
Off-Highway Trucks	530.401	0.021	0.004	528.587
Other Construction Equipment	529.554	0.021	0.004	527.743
Other General Industrial Equipment	590.044	0.024	0.005	588.026
Other Material Handling Equipment	530.593	0.021	0.004	528.778
Pavers	528.344	0.021	0.004	526.537
Paving Equipment	529.497	0.021	0.004	527.686
Plate Compactors	570.357	0.023	0.005	568.406
Pressure Washers	579.811	0.023	0.005	577.829
Pumps	570.194	0.023	0.005	568.244
Rollers	588.916	0.024	0.005	586.902
Rough Terrain Forklifts	530.541	0.021	0.004	528.726
Rubber Tired Dozers	533.998	0.022	0.004	532.172
Rubber Tired Loaders	527.966	0.021	0.004	526.161
Scrapers	530.758	0.021	0.004	528.942
Signal Boards	570.252	0.023	0.005	568.302
Skid Steer Loaders	530.187	0.021	0.004	528.374
Surfacing Equipment	528.930	0.021	0.004	527.121
Sweepers/Scrubbers	588.873	0.024	0.005	586.859
Tractors/Loaders/Backhoes	531.681	0.021	0.004	529.863
Trenchers	589.965	0.024	0.005	587.948
Welders	570.251	0.023	0.005	568.301

Notes for Table 4-9 through 4-14 are located under Table 4-14.

Table 4-12. Greenhouse Gas Emission Factors for Off-Road Equipment - 2026

Equipment	Emission Factor (g/hp-hr)			
	CO_2e [a]	CH_4	N_2O	CO_2
Aerial Lifts	588.914	0.024	0.005	586.900
Air Compressors	570.237	0.023	0.005	568.287
Bore/Drill Rigs	526.884	0.021	0.004	525.082
Cement and Mortar Mixers	572.120	0.023	0.005	570.163
Concrete/Industrial Saws	576.328	0.023	0.005	574.357
Cranes	529.271	0.021	0.004	527.461
Crawler Tractors	530.443	0.021	0.004	528.629
Crushing/Proc. Equipment	433.976	0.018	0.004	432.438
Dumpers/Tenders	573.566	0.023	0.005	571.605
Excavators	589.043	0.024	0.005	587.029
Forklifts	528.906	0.021	0.004	527.097
Generator Sets	570.277	0.023	0.005	568.327
Graders	532.637	0.022	0.004	530.815
Off-Highway Tractors	588.175	0.024	0.005	586.163
Off-Highway Trucks	530.984	0.021	0.004	529.168
Other Construction Equipment	529.352	0.021	0.004	527.541
Other General Industrial Equipment	589.895	0.024	0.005	587.877
Other Material Handling Equipment	530.550	0.021	0.004	528.736
Pavers	527.608	0.021	0.004	525.804
Paving Equipment	529.517	0.021	0.004	527.706
Plate Compactors	570.287	0.023	0.005	568.337
Pressure Washers	579.712	0.023	0.005	577.730
Pumps	570.261	0.023	0.005	568.310
Rollers	588.928	0.024	0.005	586.914
Rough Terrain Forklifts	530.704	0.021	0.004	528.889
Rubber Tired Dozers	534.378	0.022	0.004	532.550
Rubber Tired Loaders	528.221	0.021	0.004	526.415
Scrapers	530.669	0.021	0.004	528.854
Signal Boards	570.252	0.023	0.005	568.302
Skid Steer Loaders	530.435	0.021	0.004	528.621
Surfacing Equipment	529.628	0.021	0.004	527.817
Sweepers/Scrubbers	588.672	0.024	0.005	586.659
Tractors/Loaders/Backhoes	531.525	0.021	0.004	529.707
Trenchers	590.112	0.024	0.005	588.094
Welders	570.241	0.023	0.005	568.291

Notes for Table 4-9 through 4-14 are located under Table 4-14.

Table 4-13. Greenhouse Gas Emission Factors for Off-Road Equipment - 2027

Equipment	Emission Factor (g/hp-hr)			
	$CO_2{}^{e}$[a]	CH_4	N_2O	CO_2
Aerial Lifts	588.915	0.024	0.005	586.901
Air Compressors	570.272	0.023	0.005	568.322
Bore/Drill Rigs	525.773	0.021	0.004	523.974
Cement and Mortar Mixers	572.278	0.023	0.005	570.320
Concrete/Industrial Saws	576.303	0.023	0.005	574.332
Cranes	529.265	0.021	0.004	527.455
Crawler Tractors	530.824	0.021	0.004	529.009
Crushing/Proc. Equipment	434.041	0.018	0.004	432.502
Dumpers/Tenders	573.970	0.023	0.005	572.007
Excavators	589.410	0.024	0.005	587.394
Forklifts	528.879	0.021	0.004	527.070
Generator Sets	570.257	0.023	0.005	568.306
Graders	533.076	0.022	0.004	531.253
Off-Highway Tractors	588.161	0.024	0.005	586.150
Off-Highway Trucks	530.825	0.021	0.004	529.010
Other Construction Equipment	529.252	0.021	0.004	527.442
Other General Industrial Equipment	589.945	0.024	0.005	587.927
Other Material Handling Equipment	530.522	0.021	0.004	528.708
Pavers	527.614	0.021	0.004	525.809
Paving Equipment	529.880	0.021	0.004	528.068
Plate Compactors	570.268	0.023	0.005	568.318
Pressure Washers	580.355	0.023	0.005	578.370
Pumps	570.247	0.023	0.005	568.297
Rollers	589.137	0.024	0.005	587.122
Rough Terrain Forklifts	530.503	0.021	0.004	528.688
Rubber Tired Dozers	534.387	0.022	0.004	532.559
Rubber Tired Loaders	528.416	0.021	0.004	526.609
Scrapers	530.519	0.021	0.004	528.705
Signal Boards	570.249	0.023	0.005	568.298
Skid Steer Loaders	530.469	0.021	0.004	528.655
Surfacing Equipment	529.064	0.021	0.004	527.255
Sweepers/Scrubbers	588.645	0.024	0.005	586.632
Tractors/Loaders/Backhoes	531.436	0.021	0.004	529.618
Trenchers	590.197	0.024	0.005	588.179
Welders	570.247	0.023	0.005	568.297

Notes for Table 4-9 through 4-14 are located under Table 4-14.

Table 4-14. Greenhouse Gas Emission Factors for Off-Road Equipment – 2028

Equipment	Emission Factor (g/hp-hr)			
	CO_2e^a	CH_4	N_2O	CO_2
Aerial Lifts	588.917	0.024	0.005	586.903
Air Compressors	570.290	0.023	0.005	568.340
Bore/Drill Rigs	525.435	0.021	0.004	523.638
Cement and Mortar Mixers	572.290	0.023	0.005	570.333
Concrete/Industrial Saws	576.347	0.023	0.005	574.375
Cranes	529.565	0.021	0.004	527.754
Crawler Tractors	530.388	0.021	0.004	528.574
Crushing/Proc. Equipment	433.843	0.018	0.004	432.305
Dumpers/Tenders	574.192	0.023	0.005	572.228
Excavators	589.558	0.024	0.005	587.541
Forklifts	528.834	0.021	0.004	527.025
Generator Sets	570.250	0.023	0.005	568.300
Graders	533.155	0.022	0.004	531.332
Off-Highway Tractors	588.280	0.024	0.005	586.269
Off-Highway Trucks	531.114	0.021	0.004	529.297
Other Construction Equipment	528.730	0.021	0.004	526.922
Other General Industrial Equipment	589.815	0.024	0.005	587.798
Other Material Handling Equipment	530.272	0.021	0.004	528.459
Pavers	527.701	0.021	0.004	525.896
Paving Equipment	529.721	0.021	0.004	527.910
Plate Compactors	570.340	0.023	0.005	568.389
Pressure Washers	580.018	0.023	0.005	578.034
Pumps	570.294	0.023	0.005	568.344
Rollers	589.132	0.024	0.005	587.117
Rough Terrain Forklifts	530.418	0.021	0.004	528.604
Rubber Tired Dozers	534.687	0.022	0.004	532.858
Rubber Tired Loaders	528.913	0.021	0.004	527.104
Scrapers	530.423	0.021	0.004	528.609
Signal Boards	570.250	0.023	0.005	568.300
Skid Steer Loaders	530.429	0.021	0.004	528.614
Surfacing Equipment	529.125	0.021	0.004	527.315
Sweepers/Scrubbers	588.841	0.024	0.005	586.827
Tractors/Loaders/Backhoes	531.383	0.021	0.004	529.565
Trenchers	590.512	0.024	0.005	588.492
Welders	570.258	0.023	0.005	568.307

SOURCE (unless otherwise stated): California Air Resources Board, "OFFROAD2021". Source provided emission factors for aggregate model years and horsepower and were converted from tons per day to lb/hr using the provided activity. In instances where emission factors were provided for equipment which operate on both gasoline and diesel fuel, the emission factor with the larger population was selected.

a. CO_2e calculated by summing the product of the emission factors for CO_2 and CH_4 and their respective Global Warming Potentials (GWP). The GWP for CO_2 and CH_4 are 1 and 25, respectively.

Table 4-15. Default Horse-Powers and Load Factors for Off-Road Equipment

Equipment	Fuel	Horsepower (hp)	Load Factor
Aerial Lifts	Diesel	46	0.31
Air Compressors	Diesel	37	0.48
Bore/Drill Rigs	Diesel	83	0.5
Cement and Mortar Mixers	Diesel	10	0.56
Concrete/Industrial Saws	Diesel	33	0.73
Cranes	Diesel	367	0.29
Crawler Tractors	Diesel	87	0.43
Crushing/Proc. Equipment	Gasoline	12	0.85
Dumpers/Tenders	Diesel	16	0.38
Excavators	Diesel	36	0.38
Forklifts	Diesel	82	0.2
Generator Sets	Diesel	14	0.74
Graders	Diesel	148	0.41
Off-Highway Tractors	Diesel	38	0.44
Off-Highway Trucks	Diesel	376	0.38
Other Construction Equipment	Diesel	82	0.42
Other General Industrial Equipment	Diesel	35	0.34
Other Material Handling Equipment	Diesel	93	0.4
Pavers	Diesel	81	0.42
Paving Equipment	Diesel	89	0.36
Plate Compactors	Diesel	8	0.43
Pressure Washers	Diesel	14	0.3
Pumps	Diesel	11	0.74
Rollers	Diesel	36	0.38
Rough Terrain Forklifts	Diesel	96	0.4
Rubber Tired Dozers	Diesel	367	0.4
Rubber Tired Loaders	Diesel	150	0.36
Scrapers	Diesel	423	0.48
Signal Boards	Diesel	6	0.82
Skid Steer Loaders	Diesel	71	0.37
Surfacing Equipment	Diesel	399	0.3
Sweepers/Scrubbers	Diesel	36	0.46
Tractors/Loaders/Backhoes	Diesel	84	0.37
Trenchers	Diesel	40	0.5
Welders	Diesel	46	0.45

4.6 References

40 CFR 89, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 89-Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines," U.S. Environmental Protection Agency

40 CFR 98, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

40 CFR 1039, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 1039-Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines," U.S. Environmental Protection Agency

40 CFR 1068, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 1068-General Compliance Provisions for Highway, Stationary, and Nonroad Programs," U.S. Environmental Protection Agency

SCAQMD 2007, "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007

CALEEMOD 2022, "CalEEMod California Emissions Estimator Model User Guide Version 2022.1," California Air Pollution Control Officers Association (CAPCOA), April 2022

5 PORTABLE AND SEASONAL RECIPROCATING INTERNAL COMBUSTION ENGINES

- *Point* Source

5.1 Introduction

Each Air Force Installation uses portable Reciprocating Internal Combustion Engine (RICE) equipment (not self-propelled) for short-term needs and seasonal activities. Portable RICE usually have wheels, skids, carrying handles, dollies, trailers, or platforms and include generators, pumps, soil tampers, air compressors, cement mixers, etc. Due to their infrequent, irregular, and non-continuous use, emissions from portable RICE are not addressed in the *Air Emissions Guide for Stationary Sources* but are described here.

Note that, a nonroad engine can become stationary if it stays at one location for more than 12 consecutive months (even if it has a means of being transported, such as skids or wheels). For example, a generator with wheels providing power to a construction site office trailer is typically considered to be nonroad and portable; however, if that generator remains attached to the trailer at that construction site for longer than 12 consecutive months, it is regarded as a stationary ICE. Attempting to circumvent the rules by replacing the generator with another generator to power the construction trailer does not reset the 12-month clock. Additionally, a seasonal RICE can be considered stationary if it remains in a single location on a permanent basis (i.e., at least two years) and operates at that single location approximately three consecutive months (or more) each year. If there is uncertainty whether a portable or seasonal RICE is considered a stationary source, contact AFCEC/CZTQ for guidance.

In reciprocating engines, a piston moves inside a cylinder to compress an air/fuel mixture. The air/fuel mixture combusts and expands, pushing the piston through the cylinder. The piston returns, pushing out the exhaust gases, and the cycle is repeated.

Reciprocating engines may differ in design by the diameter of the cylinders in the engine, known as the bore, and the length of the linear movement of the piston in each cylinder, known as the stroke. The size of the engine is related to its displacement per cylinder, which is a measure of the volume of the cylinder multiplied by the length of the stroke. A reciprocating engine may be classified as either 4-stroke or 2-stroke. For a 4-stroke engine, the combustion cycle involves two revolutions of the crankshaft, to which the pistons are connected, and the cycle consists of four stages. The induction stroke occurs when the piston moves down within the cylinder, creating a vacuum and drawing in air or an air/fuel mixture. During the compression stroke, the piston moves up to pressurize the air or air/fuel mixture, which then ignites. The heated air expands generating a force on the piston such that it is forced downward again in what is called the power stroke. Finally, the piston moves upward again to force the exhaust gas out of the cylinder during the exhaust stroke and returns to the starting position of the induction stroke so the cycle may be repeated. 2-stroke engines can operate with just one revolution of the crankshaft because induction of the air or air/fuel mixture occurs concurrently with the release of the exhaust gas.

Detonation of the air/fuel mixture during the compression stroke may occur either through compression or spark ignition (SI). In a compression ignition (CI) engine, air is first compressed by the piston in the cylinder, which causes the temperature of the air to rise. Diesel fuel is added to the heated air and combusts since the temperature of the air is above the auto-ignition temperature of the fuel. SI engines, which use gasoline or natural gas, differ from CI engines in that the fuel/air mixture does not ignite spontaneously, but rather by a spark.

Emissions from portable engines will vary due to operating conditions such as temperature, humidity, torque, ignition timing, or even air/fuel mixture. An engine designed to operate near the stoichiometric air-to-fuel ratio is known as a rich-burn engine, whereas an engine that operates with excess oxygen is known as a lean-burn engine. Typically, lean-burn engines will produce fewer NO_X emissions than rich-burn engines. Variations in the air/fuel mixture for either engine type will occur due to engine wear or atmospheric conditions and even slight changes will dramatically affect pollutant emissions. Portable RICE act as point sources of emissions of criteria pollutants, HAPs, and GHGs. A simple control volume describing the emissions from portable RICE is provided in Figure 5-1.

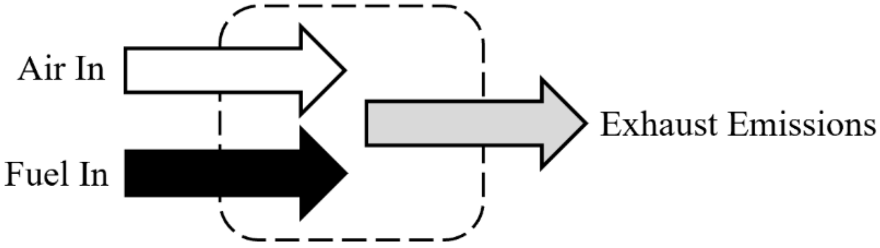


Figure 5-1. Simplified Portable RICE Control Volume

5.2 Emission Factors

Chapter 3 of AP-42 provides EFs for RICE based on the fuel used and size of the equipment. However, increasingly stringent emissions requirements have driven the manufacture of engines to produce far less emissions than those engines that served as a basis for the development of the EFs found in AP-42. Though these EFs may apply to older engines, their use in emissions calculations for newer engines may result in the overestimation of pollutant emissions. In place of the actual EFs that are provided in AP-42, the minimum required emission standards should be used to reflect the increased efficiency and reduced emissions of the newer equipment replacing older inventory.

Emissions estimates may be made utilizing the heating value and composition of the fuels used to operate the RICE. **Typical fuel data and RICE EFs for portable use equipment are provided in the "Stationary Internal Combustion" section of the *Air Emissions Guide for Air Force Stationary Sources* or the "Non-Road Engines and Equipment" section of the *Air Emissions Guide for Air Force Mobile Sources*.**

5.3 Emission Calculation

There are two methods for estimating emissions from the operation of RICE – the fuel consumption method and the load factor method. Both are described below.

5.3.1 Fuel Consumption Method

The fuel consumption method is the simplest method for calculating the emissions from portable and seasonal engines. All that is required is the total fuel consumed by that engine and the EF associated with the type of engine and fuel used. The emissions are calculated as follows:

$$\boldsymbol{E(Pol) = Q \times HV \times \frac{1}{10^6} \times EF(Pol)}$$

Equation 5-1

Where,

E(Pol) = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of fuel consumed (gal/yr) or (ft^3/yr)
HV = Heating value of the fuel used (Btu/gal) or (Btu/ft^3)
10^6 = Factor to convert Btu to MMBtu (MMBtu/Btu)
EF(Pol) = Emission factor from the Stationary or Mobile Guide (lb/MMBtu)

A detailed representation of the emissions from portable RICE engines utilizing the fuel consumption method is provided in Figure 5-2

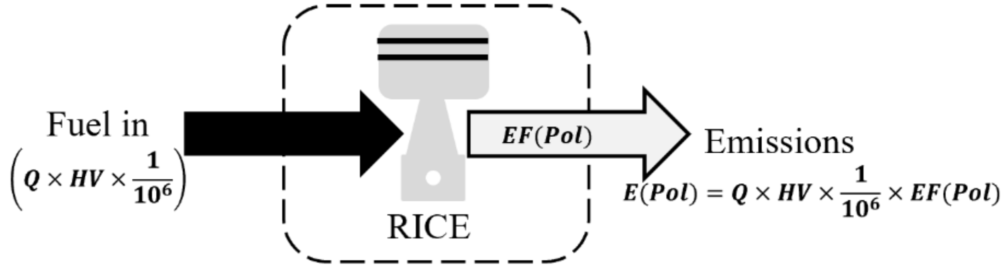


Figure 5-2. Portable and Seasonal Equipment Use Control Volume – Fuel Consumption Method

5.3.2 Load Factor Method

To calculate the most accurate emissions for portable and seasonal use engines, the first step is to gather the required data and select the appropriate EF. **To use the load factor method, the engine's rated power, operating time, and typical load factor must be known.** With the selected EF and loading factor, the RICE emissions are calculated using the following equation:

$$\boldsymbol{E(Pol) = OT \times PO \times \frac{LF}{100} \times EF(Pol)}$$

Equation 5-2

Where,

E(Pol) = Annual emissions of pollutant (lb/yr)
PO = Rated power output of the engine (hp)
LF = Engine load factor (%)
100 = Factor for converting percent to fraction (%)
OT = Annual engine operating time (hr/yr)

A detailed representation of the emissions from portable RICE utilizing the load factor method is provided in Figure 5-3.

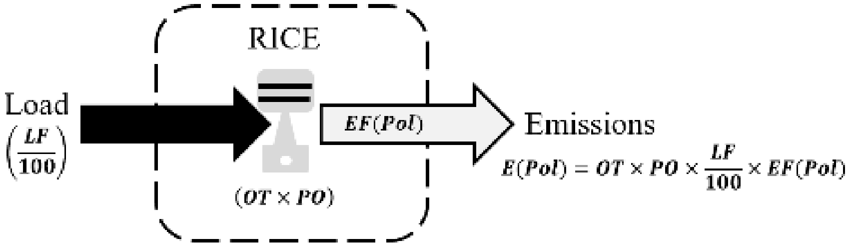


Figure 5-3. Portable and Seasonal Equipment Use Control Volume - Load Factor Method

5.4 Information Resources

To obtain data required for emissions calculations, contact the group responsible for operating/maintaining the portable and seasonal equipment, typically Civil Engineering, consult the Equipment Specification (Data or Spec) Sheets, or contact the manufacturer to request any emissions data they may have on file for those engine models. Additionally, if the engine's Brake Specific Fuel Consumption is available, through the spec sheet or from the manufacturer, use that value for EF unit conversion. Finally, since SO_X emissions are a function of the sulfur content of the fuel used, the installation's fuel supplier should be contacted to obtain the actual average sulfur content of the fuel. These sulfur content values should then be used in place of the averages provided in the Stationary or Mobile Guides.

5.5 Example Problems

5.5.1 Problem #1 – Fuel Consumption Method

A DAF Base is looking to determine the NO_X emissions from an NSPS certified model year 2013 diesel-fired portable generator for the previous year. Determine the NO_X emissions from this engine for last year using the fuel consumption method. This installation is <u>not</u> located in Alaska. The engine used a total of 12 gal of fuel last year. The engine spec sheet states that it is a 240 hp engine with a displacement of 2.1 L per cylinder.

<u>**Step 1**</u> **– Select and record EF and fuel Heating Value.** The EFs for diesel-fired engines are provided in the 2021 *Air Emissions Guide for Air Force Stationary Sources*. The NO_X EF is **7.62E-01 lb/MMBtu**. The heating value of diesel is given as **138,000 Btu/gal**.

<u>**Step 2**</u> **– Choose a calculation method and record the appropriate equation.** For demonstration purposes, the method was assigned in the problem statement, however, it should be noted that this is the most appropriate method to use since the power output and load factor are not provided while the annual fuel consumption is known.

<u>**Step 3**</u> **– Calculate emissions.** Using the fuel quantity data and EF, NO_X emissions may be calculated using Equation 5-1.

$$E(Pol) = Q \times HV \times \frac{1}{10^6} \times EF(Pol)$$

$$E(NO_X) = 12\frac{\cancel{gal}}{yr} \times 138{,}000\frac{Btu}{\cancel{gal}} \times \frac{1}{10^6}\frac{MMBtu}{Btu} \times 0.762\frac{lb}{MMBtu}$$

$$E(NO_X) = 1{,}656{,}000\frac{\cancel{Btu}}{yr} \times \frac{1}{10^6}\frac{MMBtu}{\cancel{Btu}} \times 0.762\frac{lb}{MMBtu}$$

$$E(NO_X) = 1.656\frac{\cancel{MMBtu}}{yr} \times 0.762\frac{lb}{\cancel{MMBtu}}$$

$$\boxed{\boldsymbol{E(NO_X) = 1.26\frac{lb}{yr}}}$$

5.5.2 Problem #2 – Load Factor Method

A DAF Base must calculate emissions from a stationary diesel-fired generator. Calculate the VOCs emitted by this generator from last year using the load factor method. The installation is <u>not</u> located in Alaska. The generator was manufactured in 2004 and operated for 22 hours last year. The generator spec sheet shows it is 1,250 hp, the engine has a displacement of 2.0 L per cylinder, and it is not NSPS certified. The typical load factor is approximately 74%.

Step 1 – **Select and record EF.** EFs are provided in the 2021 *Air Emissions Guide for Air Force Stationary Sources*. For a 1,250 hp diesel engine manufactured in 2004 with 2.0 L per cylinder displacement, the VOC EF is **7.16E-04 lb/hp-hr**.

Step 2 – **Choose a calculation method and record the appropriate equation.** In this example, the emissions calculation will utilize the load factor method.

Step 3 – **Calculate emissions.** Using the data above, VOC emissions are calculated as follows:

$$E(Pol) = OT \times PO \times \frac{LF}{100} \times EF(Pol)$$

$$E(VOC) = 22\,\frac{hr}{yr} \times 1250\ hp \times \frac{74\cancel{\%}}{100\cancel{\%}} \times 0.000716\,\frac{lb}{hp-hr}$$

$$E(VOC) = 22\,\frac{\cancel{hr}}{yr} \times 1250\ \cancel{hp} \times 0.74 \times 0.000716\,\frac{lb}{\cancel{hp-hr}}$$

$$\boxed{\boldsymbol{E(VOC) = 14.57\,\frac{lb}{yr}}}$$

5.6 References

40 CFR 89, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 89-Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency

40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources,” U.S. Environmental Protection Agency

40 CFR 1039, “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 1039-Control of Emissions from New and In-Use Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency

EIA 2005, “Household Vehicles Energy Use: Latest Data & Trends,” Energy Information Administration (EIA), Office of Energy Markets and End Use, U.S. Department of Energy, November 2005

SCAQMD 2007, “Software User’s Guide: URBEMIS2007 for Windows,” South Coast Air Quality Management District (SCAQMD), November 2007

Shires 2009, Shires, Theresa M.; Loughran, Christopher J.; Jones, Stephanie; Hopkins, Emily, “Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and Natural Gas Industry,” August 2009

USEPA 1996a, Section 3.3-“Gasoline and Diesel Industrial Engines,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 1996b, Section 3.4-“Large Stationary Diesel and All Stationary Dual-Fuel Engines,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996

USEPA 1998, Section 2.4-“Municipal Solid Waste Landfills,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 1998

USEPA 2000, Section 3.2-“Natural Gas-Fired Reciprocating Engines,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, July 2000

USEPA 2004, “Regulatory Announcement: Clean Air Nonroad Diesel Rule,” U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, May 2004

USEPA 2010a, “Conversion Factors for Hydrocarbon Emission Components,” U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010

USEPA 2010b, “Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling,” U.S. Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010

6 SPILLS AND RELEASES (SPRL)

- *Fugitive* Source

6.1 Introduction

Spills will inevitably occur at some point at Air Force Installations and are most often the result of fuel transfer incidents. The most common hazardous spills involve fuels such as diesel, gasoline, or JP-8 and, to a lesser extent, propane and Avgas. These types of spills are significant in nature and notification of the spill to the installation Environmental Management or the Hazardous Materials Response Team may be appropriate. Insignificant spills that result from the filling of on-road vehicle fuel tanks are calculated using the methodology described in the "Fuel Transfer" section of the *Air Emissions Guide for Air Force Stationary Sources*. Whenever a spill occurs, the majority is typically recovered during cleanup, however, the unrecovered fuel is assumed to completely evaporate into the atmosphere. **This results in the emissions of VOCs and organic HAP constituents found in the fuel.** The assumption that the unrecovered liquid completely evaporates results in conservative estimates of the emissions from these pollutants. **Emissions from fuel spills are regarded as fugitive** and a graphic representation of these emissions is shown in Figure 6-1.

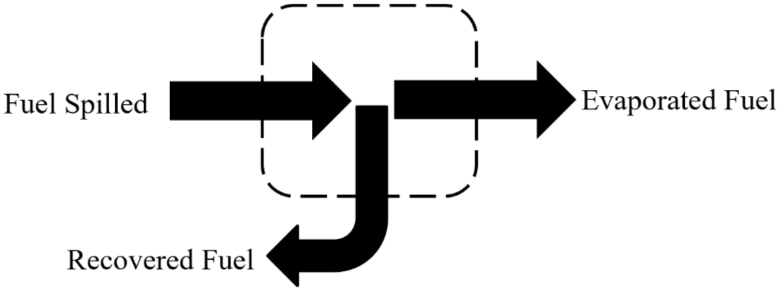


Figure 6-1. Simplified Fuel Spill Control Volume

6.2 Emissions Calculations

EFs have not been developed for fuel spills. Rather, emissions from fuel spills are calculated using a mass balance approach. The primary pollutants of concern are VOCs and organic HAPs and calculation of emissions of these pollutants are described below.

6.2.1 VOC Emissions Calculations

VOC emissions from spills are calculated using the following equation:

$$\boldsymbol{E(VOC) = (Q_S - Q_R) \times \rho = (Q_S - Q_R) \times SG \times 8.33}$$

Equation 6-1

Where,

E(VOC) = Annual emissions of VOCs from spills (lb/yr)
Q_S = Annual quantity of liquid spilled (gal/yr)
Q_R = Annual quantity of liquid recovered (gal/yr)
ρ = Density of liquid (lb/gal)
SG = Specific gravity of liquid
8.33 = Density of water at 70°F (lb/gal)

Note that density of a liquid is the product of the specific gravity and the density of water.

A more detailed control volume describing the calculation of emissions from fuel spills is given in Figure 6-2 below.

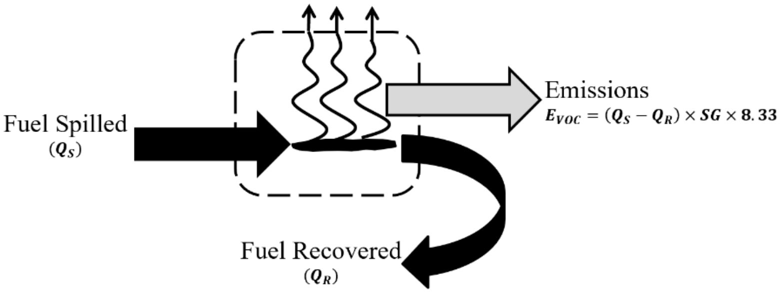


Figure 6-2. Fuel Spill Control Volume

The fuel density will vary between fuels and from region to region. For the most accurate density values contact the fuel supplier for this information. In the absence of this data, common fuel densities are provided in Table 6-1.

Table 6-1. Average Densities of Fuels Commonly Used at Air Force Installations

Fuel Type	Density (lb/gal)
Diesel	7.14
MOGAS	6.15
Jet A/JP-8	6.71 [a]
LPG	4.41

SOURCE (unless otherwise noted): “Household Vehicles Energy Use: Latest Data & Trends,” Energy Information Administration, Office of Energy Markets and End Use, U.S. Department of Energy, November 2005. MOGAS-Automotive Gasoline. LPG-Liquified Petroleum Gasoline.

a. SOURCE: Petroleum Quality Information System Fuels Data, Defense Logistics Agency, Defense Energy Support Center, 2001 – 2013. Values were calculated as the average weighted average density for years 2001 – 2013.

6.2.2 HAP Emissions Calculations

When calculating emissions from fuel spills, the conservative assumption is that all unrecovered fuel evaporates. The organic HAP emissions are calculated based on the liquid-phase speciation of the fuel. This is accomplished using the weight fraction of the HAP as shown in the following equation.

$$\boldsymbol{E(HAP) = E(VOC) \times \frac{WP(HAP)}{100}}$$

Equation 6-2

Where,

E(HAP) = Annual emissions of specific HAP (lb/yr)
WP(HAP) = Weight percent of the HAP in the liquid fuel (%)

As with fuel density, there is some variation in the HAP weight percent between fuels. Contact the fuel supplier or review the SDS for guidance in determining the correct weight percent for each HAP constituent to calculate a more accurate emission value. If this data is unavailable, typical HAP concentrations are provided in Table 6-2.

Table 6-2. HAP Speciation of Fuels Commonly Used at Air Force Installations

Compound	Molecular Weight	Vapor Pressure (psi) [a]	Typical wt. %					
			Diesel		Gasoline		JP-8/Jet A [b]	
			Liquid Phase	Vapor Phase [c]	Liquid Phase	Vapor Phase [c]	Liquid Phase	Vapor Phase [c]
Anthracene	178.22	1.27E-07	2.82E-03 [d]	5.76E-08	---	---	---	---
Benzene	78.11	1.51E+00	8.00E-04	1.94E-01	1.80E+00	6.10E-01	3.36E-02	1.55E+00
1,3-Butadiene	54.09	3.61E+01	---	---	2.19E-04 [d]	1.78E-03	---	---
Cumene (Isopropylbenzene)	120.20	6.93E-02	---	---	5.00E-01	7.79E-03	1.80E-01	3.81E-01
Dibenzofuran	168.20	4.80E-05	1.64E-02 [d]	1.26E-04	---	---	---	---
Ethylbenzene	106.17	1.48E-01	1.30E-02	3.10E-01	1.40E+00	4.67E-02	1.58E-01	7.16E-01
Fluorene	166.21	1.16E-05	2.94E-02 [d]	5.48E-05	---	---	3.42E-03	1.21E-06
Hexane	86.17	2.44E+00	1.00E-04	3.91E-02	1.00E+00	5.48E-01	---	---
Isooctane (2,2,4-Trimethyl Pentane)	114.23	5.38E-02	---	---	4.00E+00	4.84E-02	1.22E-03	2.00E-03
Naphthalene	128.20	3.94E-03	3.39E-01 [d]	2.15E-01	1.74E-01 [d]	1.54E-04	2.66E-01	3.20E-02
Phenanthrene	178.22	2.34E-06	3.22E-02 [d]	1.21E-05	---	---	---	---
Phenylbenzene (1,1'-biphenyl)	154.21	3.78E-04	---	---	---	---	6.74E-02	7.79E-04
Pyrene	202.24	8.70E-08	3.62E-02 [d]	5.06E-07	---	---	1.24E-05	3.31E-11
Toluene	92.13	4.25E-01	3.20E-02	2.19E+00	7.00E+00	6.69E-01	2.18E-01	2.83E+00
Xylenes	106.17	1.30E-01	2.90E-01	6.06E+00	7.00E+00	2.05E-01	1.18E+00	4.69E+00

SOURCE (unless otherwise stated): Data taken from USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005. wt%=weight percent.

a. Vapor pressures of pure species used in calculations were taken at 70°F and provided either by TANKS, the Hazardous Substance Data Bank (HSDB), or were calculated using Antoine's equation constants provided either by the National Institute of Standards and Technology (NIST) or Perry's Chemical Engineer's Handbook, 7th Ed., Perry, Robert H., 1997.

b. SOURCE: "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996. An average density of 6.71 pounds per gallon (lb/gal) was used for unit conversion.

c. The vapor phase speciation data was estimated using the liquid phase speciation data and equations found in Section 7.1.4 of AP-42, Fifth Edition, Volume I last updated November 2006.

d. SOURCE: SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014. For diesel, profile 4673 was referenced. For gasoline, profile 8748 was referenced.

"---" Indicates No Data Available.

6.3 Information Resources

For information regarding fuel spills, including type of fuel, quantity spilled, and quantity recovered, contact the base Environmental Management or CEV office. Additionally, the on-base Fire Department, Fuels Management, or Hazardous Materials Response Team may serve as points of contact for information regarding fuel spills.

6.4 Example Problem

After contacting the CEV office, it was reported that there was a total of five significant JP-8 fuel spills on base for the previous year. It was estimated that for the five spills, a total of 625 gallons of JP-8 was spilled, of which an estimated 450 gallons were recovered. Determine the VOC and total HAP emissions from these spills for the previous year.

__Step 1__ – **Record the density of the fuel.** The problem statement does not provide an estimate of the density of the JP-8 spilled. After reviewing Table 6-1, it is shown that the average density of JP-8 is **6.71 lb/gal.**

__Step 2__ – **Calculate VOC emissions.** VOC emissions are calculated using the data given in the problem statement, the density given in Step 1, and Equation 6-1 as shown:

$$E(VOC) = (Q_S - Q_R) \times \rho$$

$$E(VOC) = \left(625\,\frac{gal}{yr} - 450\,\frac{gal}{year}\right) \times 6.71\,\frac{lb}{gal}$$

$$E(VOC) = \left(175\,\frac{\cancel{gal}}{year}\right) \times 6.71\,\frac{lb}{\cancel{gal}}$$

$$\boxed{\boldsymbol{E(VOC) = 1,174.25\,\frac{lb}{yr}}}$$

__Step 3__ – **Select and record the wt. % of each HAP in JP-8.** Using Table 6-2, the HAP constituents of JP-8 and their respective wt. % are: **benzene 3.36E-02, cumene 1.80E-01, ethylbenzene 1.58E-01, fluorene 3.42E-03, isooctane 1.22E-03, naphthalene 2.66E-01, phenylbenzene 6.74E-02, pyrene 1.24E-05, toluene 2.18E-01, and xylene 1.18E+00.**

__Step 4__ – **Calculate emissions of each HAP.** HAP emissions may be calculated using the total VOC emissions calculated in Step 2, the weight percent of each HAP as recorded in Step 3, and Equation 6-2.

$$\boldsymbol{E(HAP)} = E(VOC) \times \frac{WP(HAP)}{100}$$

$$\boldsymbol{E(Benzene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.0336\cancel{\%}}{100\cancel{\%}}$$

$$\boldsymbol{E(Benzene) = 0.39\,\frac{lb}{yr}}$$

The remaining HAPs were similarly calculated, and the results shown below.

$$\boldsymbol{E(Cumene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.18\cancel{\%}}{100\cancel{\%}} = \boldsymbol{2.11\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Ethylbenzene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.158\cancel{\%}}{100\cancel{\%}} = \boldsymbol{1.86\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Fluorene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.00342\cancel{\%}}{100\cancel{\%}} = \boldsymbol{0.04\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Isooctane)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.00122\cancel{\%}}{100\cancel{\%}} = \boldsymbol{0.01\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Naphthalene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.266\cancel{\%}}{100\cancel{\%}} = \boldsymbol{3.12\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Phenylbenzene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.0674\cancel{\%}}{100\cancel{\%}} = \boldsymbol{0.79\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Pyrene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.0000124\cancel{\%}}{100\cancel{\%}} = \boldsymbol{0.0001\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Toluene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{0.218\cancel{\%}}{100\cancel{\%}} = \boldsymbol{2.56\,\frac{lb}{yr}}$$

$$\boldsymbol{E(Xylene)} = 1{,}174.25\,\frac{lb}{yr} \times \frac{1.18\cancel{\%}}{100\cancel{\%}} = \boldsymbol{13.86\,\frac{lb}{yr}}$$

<u>**Step 5**</u> **– Calculate total HAPs emitted.** Sum the HAPs calculated in Step 4.

$$E(Total\ HAP) = \sum[E(HAP)_i + \cdots + E(HAP)_n]$$

$$E(Total\ HAP) = (2.11 + 1.86 + 0.04 + 0.01 + 3.12 + 0.79 + 0.0001 + 2.56 + 13.86)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total\ HAP) = 24.4\,\frac{lb}{yr}}}$$

6.5 References

DLA 2006, “Petroleum Quality Information System Fuels Data (2005),” Defense Logistics Agency (DLA), Defense Energy Support Center, Technology and Standardization Division, 2006

EIA 2005, “Household Vehicles Energy Use: Latest Data & Trends,” Energy Information Administration (EIA), Office of Energy Markets and End Use, U.S. Department of Energy, November 2005

Mayfield 1996, “JP-8 Composition and Variability,” Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996

USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005

USEPA 2014, SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014

7 HOT MIX ASPHALT PLANTS (HMA)

- *Point* Source – From ducted sources, i.e., dryer
- *Fugitive* Source – From open sources, i.e., yard emissions

7.1 Introduction

Hot Mix Asphalt (HMA) plants on Air Force Installations are typically associated with large-scale paving operations. Although uncommon, they have the potential to be a substantial contributor to emissions during the year. Emissions from HMA plants are addressed here because they are usually temporary in nature. **However, if the HMA plant is in place for longer than one year, it is considered a stationary source and should be added to the stationary source inventory.**

HMA paving materials consist of size-graded, high-quality aggregate (which often includes reclaimed asphalt pavement [RAP]) and liquid asphalt cement. The materials are mixed in precise quantities and heated to produce the HMA. The means by which the materials are mixed classify the HMA plant as either a batch or drum mix plant. In batch mix plants, the aggregate is dried before being added to a mixer with liquid asphalt cement. In a drum mix plant, the aggregate is dried and mixed with the liquid asphalt cement within the same rotary drum.

An HMA mixing plant may be constructed as either a permanent, a skid-mounted, or a portable plant. Although most plants have the capability to use either gaseous fuels or fuel oil, between 70 and 90 percent of HMA is produced using natural gas as the preferred fuel to dry and heat the aggregate. **Emissions of concern from HMA paving operations include criteria pollutants, HAPs, and GHGs. The primary source of emissions includes fugitive and ducted emissions from dryers, hot screens, and mixers associated with production of the HMA.** Emissions result from both production and pre-production activities. Pre-production fugitive dust emissions include aggregate material handling, aggregate processing operations, and vehicular traffic. Emissions associated with vehicular traffic are considered mobile in nature and are addressed within the *Air Emissions Guide to Air Force Mobile Sources*. Emissions associated with on-site asphalt storage tanks may be estimated by referencing the "Storage Tanks" section of the *Air Emissions Guide for Air Force Stationary Sources*. A graphical representation of emissions from HMA plants is provided in Figure 7-1.

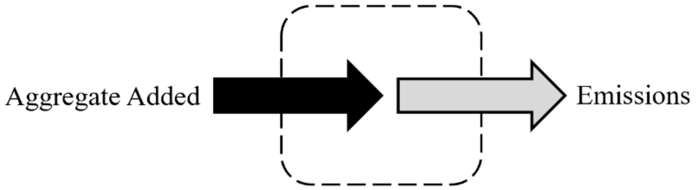


Figure 7-1. Simplified HMA Plants Emissions Control Volume

7.2 NSPS Applicability

Hot mix asphalt plants are subject to NSPS as outlined in 40 CFR 60 subpart I. This section states that no hot mix asphalt plant shall emit more than 90 mg/dscm of particulate matter or exhibit 20% or greater opacity. This section continues by outlining the requirements for proving that the facility complies with these standards. These requirements state that EPA Method 5 is used to determine PM concentration using a 60-minute run time and a sample volume of 0.90 dscm. Opacity is determined by using EPA Method 9 and procedures in 60.11.

7.3 Warm Mix Asphalt (WMA) Plants

WMA is a relatively new asphalt production method. It has the benefit of utilizing lower production temperatures than HMA. Studies indicate that the ability to produce asphalt at a lower temperature result in fewer emissions. Per *Engineering Technical Letter 11-3: Warm Mix Asphalt (WMA)*, the Air Force allows WMA to be used for asphalt work on roads and parking lots subject to non-airfield State DOT specifications if the DOT allows WMA. At this time, there are no specific EFs published for WMA. However, there are percent reductions that represent the amount of emission produced from WMA plants relative to HMA plants.

7.4 Emission Factors

In all cases, utilizing EPA Method 5 site-specific stack sampling data is the preferred method of estimating emissions from HMA operations. In the absence of such data, EFs have been developed for production related fugitive and ducted emissions. Criteria pollutant EFs are presented in Table 7-1. EFs for WMA plants were developed by applying percent reductions to HMA plant operations. These are provided in Table 7-2. At this time, no EFs have been developed for HAPs from WMA plants. Therefore, it is appropriate to use HMA HAP EFs as a surrogate. Speciated HAP EFs for HMA are provided in Table 7-3. Each state may have alternate requirements and the appropriate state or local agency should be contacted prior to calculating emissions to ensure compliance.

Table 7-1. Criteria Pollutant Emission Factors for Batch Mix and Drum Mix HMA Plants

Hot Mix Asphalt Process [SCC]	Emission Factors (lb/ton)							
	NO_X	CO	SO_X	Pb	VOC	PM_{10} [Controlled] [a]	$PM_{2.5}$ [Controlled] [a]	CO_2e [b]
Batch Mix HMA Plants								
Natural Gas-Fired [3-05-002-45]	2.50E-02	4.00E-01	4.60E-03	8.90E-07	8.20E-03	4.50E+00 [2.70E-02]	2.70E-01 [8.30E-03]	3.72E+01
No. 2 Fuel Oil [3-05-002-46]	1.20E-01	4.00E-01	8.80E-02	8.90E-07	8.20E-03	4.50E+00 [2.70E-02]	2.70E-01 [8.30E-03]	3.72E+01
Waste Oil/No. 6 Oil-Fired [3-05-002-47]	1.20E-01	4.00E-01	8.80E-02	1.00E-05	3.60E-02	4.50E+00 [2.70E-02]	2.70E-01 [8.30E-03]	3.72E+01
Drum Mix HMA Plants								
Natural Gas-Fired [3-05-002-55,-56,-57]	2.60E-02	1.30E-01	3.40E-03	6.20E-07	3.20E-02	6.50E+00 [2.30E-02]	1.50E+00 [2.90E-03]	3.33E+01
No. 2 Fuel Oil [3-05-002-58,-59,-60]	5.50E-02	1.30E-01	1.10E-02	1.50E-05	3.20E-02	6.50E+00 [2.30E-02]	1.50E+00 [2.90E-03]	3.33E+01
Waste Oil/No. 6 Oil-Fired [3-05-002-61,-62,-63]	5.50E-02	1.30E-01	5.80E-02	1.50E-05	3.20E-02	6.50E+00 [2.30E-02]	1.50E+00 [2.90E-03]	3.33E+01

SOURCE: Section 11.1 – "Hot Mix Asphalt Plants," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, March 2004.

a. Control device used: fabric filter.

b. CO_2e calculated by summing the product of the emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The emission factors were taken from AP-42 and the GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25, respectively.

Table 7-2. Criteria Pollutant Emission Factors for Batch Mix and Drum Mix WMA Plants

Warm Mix Asphalt Process	Emission Factors (lb/ton)							
	NO_X	CO	SO_X	Pb [a]	VOC	PM_{10} [Controlled] [b]	$PM_{2.5}$ [Controlled] [b]	CO_2e [c]
Batch Mix HMA Plants								
Natural Gas-Fired	8.75E-03	3.20E-01	2.99E-03	8.90E-07	4.10E-03	3.49E+00 [2.09E-02]	2.09E-01 [6.43E-03]	2.42E+01
No. 2 Fuel Oil	4.20E-02	3.20E-01	5.72E-02	8.90E-07	4.10E-03	3.49E+00 [2.09E-02]	2.09E-01 [6.43E-03]	2.42E+01
Waste Oil/No. 6 Oil-Fired	4.20E-02	3.20E-01	5.72E-02	1.00E-05	1.80E-02	3.49E+00 [2.09E-02]	2.09E-01 [6.43E-03]	2.42E+01
Drum Mix HMA Plants								
Natural Gas-Fired	9.10E-03	1.04E-01	2.21E-03	6.20E-07	1.60E-02	5.04E+00 [1.78E-02]	1.16E+00 [2.25E-03]	2.18E+01
No. 2 Fuel Oil	1.93E-02	1.04E-01	7.15E-03	1.50E-05	1.60E-02	5.04E+00 [1.78E-02]	1.16E+00 [2.25E-03]	2.18E+01
Waste Oil/No. 6 Oil-Fired	1.93E-02	1.04E-01	3.77E-02	1.50E-05	1.60E-02	5.04E+00 [1.78E-02]	1.16E+00 [2.25E-03]	2.18E+01

SOURCE: Colonel Lambert, A. (2011). Engineering Technical Letter (ETL) 11-3: Warm Mix Asphalt (WMA). Headquarters Air Force Civil Engineer Support Agency. Percent reductions in source document were applied to emission factors for HMA plants.

a. There were no lead reductions applicable from source document. Therefore, HMA values are used as a surrogate.

b. Control device used: fabric filter.

c. CO_2e calculated by summing the product of the emission factors for CO_2, N_2O, and CH_4 and their respective Global Warming Potentials (GWP). The emission factors were taken from AP-42 and the GWP for CO_2, N_2O, and CH_4 are 1, 298, and 25, respectively.

Table 7-3. HAP Pollutant Emission Factors for HMA Plants

Compound	Emission Factors (lb/ton)				
	Batch Dryer		Drum Dryer		
	Natural Gas or No. 2 Fuel Oil	Waste Oil or No. 6 Fuel Oil	Natural Gas	No. 2 Fuel Oil	Waste Oil
Acenaphthene	9.00E-07	9.00E-07	1.40E-06	1.40E-06	1.40E-06
Acenaphthylene	5.80E-07	5.80E-07	8.60E-06	2.20E-05	2.20E-05
Acetaldehyde	3.20E-04	3.20E-04	---	---	1.30E-03
Acrolein	---	---	---	---	2.60E-05
Anthracene	2.10E-07	2.10E-07	2.20E-07	3.10E-06	3.10E-06
Antimony	---	---	1.80E-07	1.80E-07	1.80E-07
Arsenic	4.60E-07	4.60E-07	5.60E-07	5.60E-07	5.60E-07
Benzene	2.80E-04	2.80E-04	3.90E-04	3.90E-04	3.90E-04
Benzo(a)anthracene	4.60E-09	4.60E-09	2.10E-07	2.10E-07	2.10E-07
Benzo(a)pyrene	3.10E-10	3.10E-10	9.80E-09	9.80E-09	9.80E-09
Benzo(b)fluoranthene	9.40E-09	9.40E-09	1.00E-07	1.00E-07	1.00E-07
Benzo(g,h,i)perylene	5.00E-10	5.00E-10	4.00E-08	4.00E-08	4.00E-08
Benzo(k)fluoranthene	1.30E-08	1.30E-08	4.10E-08	4.10E-08	4.10E-08
Benzo(e)pyrene	---	---	---	1.10E-07	1.10E-07
Beryllium	1.50E-07	1.50E-07	---	---	---
Cadmium	6.10E-07	6.10E-07	4.10E-07	4.10E-07	4.10E-07
Chromium	5.70E-07	5.70E-07	5.50E-06	5.50E-06	5.50E-06
Chromium VI	4.80E-08	4.80E-08	4.50E-07	4.50E-07	4.50E-07
Chrysene	3.80E-09	3.80E-09	1.80E-07	1.80E-07	1.80E-07
Cobalt	---	---	2.60E-08	2.60E-08	2.60E-08
Dibenz(a,h)anthracene	9.50E-11	9.50E-11	---	---	---
Dioxans - Total	---	---	---	1.66E-10	1.66E-10
Ethylbenzene	2.20E-03	2.20E-03	2.40E-04	2.40E-04	2.40E-04
Fluoranthene	1.60E-07	2.40E-05	6.10E-07	6.10E-07	6.10E-07
Fluorene	1.60E-06	1.60E-06	3.80E-06	1.10E-05	1.10E-05
Formaldehyde	7.40E-04	7.40E-04	3.10E-03	3.10E-03	3.10E-03
Furans - Total	---	---	---	3.06E-03	3.06E-03
Hexane	---	---	9.20E-04	9.20E-04	9.20E-04
Indeno (1,2,3-cd)pyrene	3.00E-10	3.00E-10	7.00E-09	7.00E-09	7.00E-09
Lead	8.90E-07	1.00E-05	6.20E-07	1.50E-05	1.50E-05
Manganese	6.90E-06	6.90E-06	7.70E-06	7.70E-06	7.70E-06
Mercury	4.10E-07	4.10E-07	2.40E-07	2.60E-06	2.60E-06
Methyl Chloroform	---	---	4.80E-05	4.80E-05	4.80E-05
2-Methylnaphthalene	7.10E-05	7.10E-05	7.40E-05	1.70E-04	1.70E-04
Naphthalene	3.60E-05	3.60E-05	9.00E-05	6.50E-04	6.50E-04
Nickel	3.00E-06	3.00E-06	6.30E-05	6.30E-05	6.30E-05
Perylene	---	---	8.80E-09	8.80E-09	8.80E-09
Phenanthrene	2.60E-06	3.70E-05	7.60E-06	2.30E-05	2.30E-05
Phosphorus	---	---	2.80E-05	2.80E-05	2.80E-05
Propionaldehyde	---	---	---	---	1.30E-04
Pyrene	6.20E-08	5.50E-05	5.40E-07	3.00E-06	3.00E-06
Quinone	2.70E-04	2.70E-04	---	---	1.60E-04
Selenium	4.90E-07	4.90E-07	3.50E-07	3.50E-07	3.50E-07
Toluene	1.00E-03	1.00E-03	1.50E-04	2.90E-03	2.90E-03
2,2,4-Trimethylpentane	---	---	4.00E-05	4.00E-05	4.00E-05
Xylene	2.70E-03	2.70E-03	2.00E-04	2.00E-04	2.00E-04

SOURCE: Section 11.1 – "Hot Mix Asphalt Plants," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, March 2004.

"---" – Indicates No Data Available.

7.5 Emissions Calculations

Emissions may be calculated by multiplying the appropriate EF by the activity of the HMA production rate and the hours the plant was in operation during the year, as follows:

$$\boldsymbol{E(Pol) = Q \times EF(Pol)}$$

Equation 7-1

Where,

E(Pol) = Annual emissions of pollutant (lb/yr)
Q = Annual quantity of asphalt produced (ton/yr)
EF(Pol) = Emission factor for a specific pollutant (lb/ton)

A detailed control volume depicting emissions from HMA plants is provided in Figure 7-2.

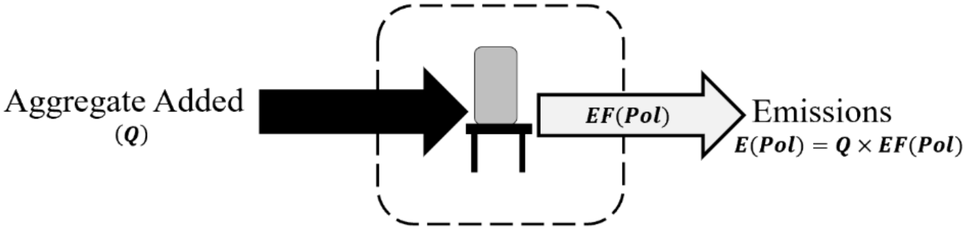


Figure 7-2. HMA Control Volume

7.6 Information Resources

HMA paving operations on base are performed by Base Civil Engineering or by a commercial contractor. Base Civil Engineering should have, or be able to obtain, the information necessary to calculate emissions from HMA plant operations.

7.7 Example Problem

A DAF Base needs to calculate formaldehyde emissions from their HMA paving operations on base. Base Civil Engineering reports that the on-base HMA plant is a batch mix plant that uses natural gas for aggregate heating. The maximum production rate was 190 tons/hr and the plant was estimated to have operated for approximately 1,100 hours/yr.

Step 1 – **Calculate the annual quantity of asphalt produced.** The problem provided the maximum production rate and total annual operating time. The quantity may be conservatively estimated as follows:

$$Q = Max\ Production\ rate \times Operating\ Time$$

$$\boldsymbol{Q} = 190\frac{ton}{\cancel{hr}} \times 1{,}100\frac{\cancel{hr}}{yr} = \boldsymbol{209{,}000\frac{ton}{yr}}$$

Step 2 – **Select and record the appropriate EF.** Table 7-3 lists the EF of formaldehyde for batch dryers utilizing natural gas as **7.40E-04 lb/ton** of HMA produced.

Step 3 – **Calculate emissions.** Formaldehyde emissions associated with HMA paving operations are calculated using the recorded EF, Equation 7-1, and the information provided as follows:

$$E(Pol) = Q \times EF(Pol)$$

$$E(Formaldeyde) = 209{,}000\frac{\cancel{ton}}{yr} \times 0.00074\frac{lb}{\cancel{ton}}$$

$$\boxed{\boldsymbol{E(Formaldeyde) = 154.66\ \frac{lb}{yr}}}$$

7.8 References

40 CFR 98 Subpart C. “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources,” U.S. Environmental Protection Agency

Colonel Lambert, A. 2011. Engineering Technical Letter (ETL) 11-3: Warm Mix Asphalt (WMA). Headquarters Air Force Civil Engineer Support Agency. August 2011

USEPA 2000, “Hot Mix Asphalt Plants: Emission Assessment Report (EPA-454/R-00-019),” U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards, December 2000

USEPA 2004, Section 11.1-“Hot Mix Asphalt Plants,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, March 2004.

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8 CONCRETE BATCH PLANT (CB)

- *Point* Source – From ducted sources, i.e., dryer
- *Fugitive* Source – From open sources, i.e., yard emissions

8.1 Introduction

Concrete batch (CB) plants at Air Force Installations are typically associated with large-scale construction operations. Concrete is mostly composed of water, cement, sand (fine aggregate), and coarse aggregate. Although uncommon, they have the potential to be a substantial contributor to emissions during the year. Emissions from concrete batch plants are addressed here because they usually accompany activities relating to construction or repair. However, if a concrete plant is in place for longer than one year, it must be considered a stationary source and added to the stationary source inventory.

There are two types of concrete batch plants: truck mix and central mix plants. Truck mix are also referred to as dry mix plants. The dry ingredients, such as sand, gravel, and cement, are mixed in a chute and subsequently deposited into a mixer truck. Water is discharged through the chute and into the mixer truck, and the material is agitated during transportation to the job site. Central mix plants are also referred to as wet mix plants. Central mix plants have a central mixing device in which all ingredients, including the water, are blended and then deposited into a vehicle for transportation to the job site. A simple control volume is shown in Figure 8-1.

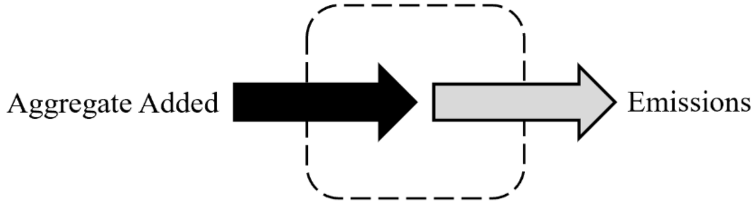

Figure 8-1. Simplified Concrete Batch Plant Emissions Control Volume

8.2 Emission Factors

EFs have been developed for material handling processes associated with CB plants. Algorithms and EFs used by the Air Force are generally from AP-42. Concrete batch plant metallic HAP EFs are presented in Table 8-1. Plant-wide particulate EFs associated central and truck mix concrete are provided in Table 8-2

Table 8-1. Concrete Batch Plant Metallic HAP Emission Factors

Pollutant	Fabric Filter Controlled Emission Factors (lb/ton) [a]				Uncontrolled Emission Factors (lb/ton) [a]			
	Cement Silo Filling	Cement Supplement Silo Filling	Central Mix Batching [b]	Truck Loading [c]	Cement Silo Filling	Cement Supplement Silo Filling	Central Mix Batching [b]	Truck Loading [c]
	SCC 3-05-011-07	SCC 3-05-011-17	SCC 3-05-011-09	SCC 3-05-011-10	SCC 3-05-011-07	SCC 3-05-011-17	SCC 3-05-011-09	SCC 3-05-011-10
Arsenic	4.24E-09	1.00E-06	2.96E-07	6.02E-07	1.68E-06	ND	8.38E-06	1.22E-05
Beryllium	4.86E-10	9.04E-08	ND	1.04E-07	1.79E-08	ND	ND	2.44E-07
Cadmium	ND	1.98E-10	7.10E-10	9.06E-09	2.34E-07	ND	1.18E-08	3.42E-08
Total Chromium	2.90E-08	1.22E-06	1.27E-07	4.10E-06	2.52E-07	ND	1.42E-06	1.14E-05
Lead	1.09E-08	5.20E-07	3.66E-08	1.53E-06	7.36E-07	ND	3.82E-07	3.62E-06
Manganese	1.17E-07	2.56E-07	3.78E-06	2.08E-05	2.02E-04	ND	6.12E-05	6.12E-05
Nickel	4.18E-08	2.28E-06	2.48E-07	4.78E-06	1.76E-05	ND	3.28E-06	1.19E-05
Total Phosphorus	ND	3.54E-06	1.20E-06	1.23E-05	1.18E-05	ND	2.02E-05	3.84E-05
Selenium	ND	7.24E-08	ND	1.13E-07	ND	ND	ND	2.62E-06

SOURCE: Section 11.12 – "Concrete Batching," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2006.

a. All emission factors are in lb of pollutant per ton of material loaded unless noted otherwise. Loaded material includes coarse aggregate, sand, cement, cement supplement, and the surface moisture associated with these materials.

b. Typical central mix operation emission factor units are lb of pollutant per ton of cement and cement supplement.

c. Typical truck mix loading operation emission factor units are lb of pollutant per ton of cement and cement supplement.

ND = No Data.

Table 8-2. Plant-Wide Emissions of Central and Truck Mix Concrete

Pollutant-Emitting Activity	Uncontrolled		Controlled	
	PM_{10}	$PM_{2.5}$ [a]	PM_{10}	$PM_{2.5}$ [a]
	lb/yd^3	lb/yd^3	lb/yd^3	lb/yd^3
Aggregate delivery to ground storage SCC 3-05-011-21	0.0031	0.0021	0.0031	0.0021
Sand delivery to ground storage SCC 3-05-011-22	0.0007	0.0005	0.0007	0.0005
Aggregate transfer to conveyor SCC 3-05-011-23	0.0031	0.0021	0.0031	0.0021
Sand transfer to conveyor SCC 3-05-011-24	0.0007	0.0005	0.0007	0.0005
Aggregate transfer to elevated storage SCC 3-05-011-04	0.0031	0.0021	0.0031	0.0021
Sand transfer to elevated storage SCC 3-05-011-05	0.0007	0.0005	0.0007	0.0005
Cement delivery to Silo SCC 3-05-011-07 (controlled)	0.0001	0.0001	0.0001	0.0001
Cement supplement delivery to Silo SCC 3-05-011-17 (controlled)	0.0002	0.0001	0.0002	0.0001
Weigh hopper loading SCC 3-05-011-08	0.0038	0.0026	0.0038	0.0026
Central mix loading [b] SCC 3-05-011-09	0.0440	0.0297	0.0016	0.0010
Truck mix loading [b] SCC 3-05-011-10	0.0874	0.0589	0.0074	0.0050

SOURCE: Section 11.12 – "Concrete Batching," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2006.

a. $PM_{2.5}$ is calculated using $PM_{2.5}$ fractions given by California Emission Inventory Development and Reporting System (CEIDARS).

b. Central and truck mix loading emission factors were calculated with default data using Equation 11.12-2 from the reference source.

8.3 Emissions Calculations

Emissions may be calculated by multiplying the appropriate EF by the emission rate of the pollutant-emitting activity and the hours the plant was in operation during the year, as follows:

$$\boldsymbol{E(Pol) = Q \times EF(Pol)}$$

Equation 8-1

Where,

E(Pol) = Annual emissions of pollutant (ton/yr)
Q = Annual quantity of asphalt produced (ton/yr)
EF(Pol) = Emission factor for a specific pollutant (lb/ton)

A detailed control volume depicting the emissions from concrete batch plants is given in Figure 8-2.

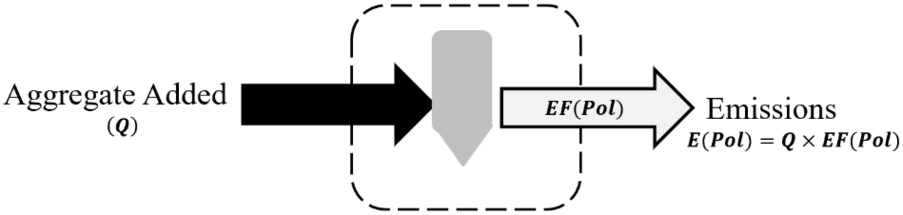

Figure 8-2. Concrete Batch Plant Control Volume

8.4 Information Resources

CB plant operations on an installation are performed by base Civil Engineering or by a commercial contractor. Base Civil Engineering should have, or be able to obtain, the information necessary to calculate emissions from CB plant operations.

8.5 Example Problems

8.5.1 Problem #1

A DAF Base needs to calculate total chromium emissions from their central mix batching operations on base. Base Civil Engineering reports that the on-base CB plant is a controlled central mix plant. The maximum production rate was 210 tons/hr and the plant was estimated to have operated for approximately 900 hours/yr.

<u>Step 1</u> – Calculate the annual quantity of concrete produced. The problem provided the maximum production rate and total annual operating time. The quantity may be conservatively estimated as follows:

$$Q = Max\ Production\ Rate \times Operating\ Time$$

$$\boldsymbol{Q} = 210 \frac{ton}{\cancel{hr}} \times 900 \frac{\cancel{hr}}{yr} = \mathbf{189,000} \frac{\boldsymbol{ton}}{\boldsymbol{yr}}$$

<u>Step 2</u> – Select and record the appropriate EF. Table 8-1 lists the EF of total chromium for controlled central mix batching as **1.27E-07 lb/ton** of concrete.

<u>Step 3</u> – Calculate emissions. Total chromium emissions associated with central mix batching operations are calculated using the recorded EF, Equation 8-1, and the information provided as follows:

$$E(Pol) = Q \times EF(Pol)$$

$$E(Chromium) = 0.000000127 \frac{lb}{\cancel{ton}} \times 189{,}000 \frac{\cancel{ton}}{yr}$$

$$\boxed{\boldsymbol{E(Chromium) = 0.024 \frac{lb}{yr}}}$$

8.5.2 Problem #2

A DAF Base needs to calculate $PM_{2.5}$ emissions from their CB plant operations that include weigh hopper loading and central mix loading. Base Civil Engineering reports that the on-base CB plant is a controlled central mix plant. The maximum production rate was 210 tons/hr and the plant was estimated to have operated for approximately 900 hr/yr. According to Chapter 11 of AP-42, for conversion purposes, there are 4,024 pounds of material in one cubic yard of concrete.

<u>Step 1</u> – Calculate the annual quantity of concrete produced. The problem provided the maximum production rate and total annual operating time. The quantity may be conservatively estimated as follows:

$$Q = Max\ Production\ Rate \times Operating\ Time$$

$$\boldsymbol{Q} = 210 \frac{ton}{\cancel{hr}} \times 900 \frac{\cancel{hr}}{yr} = \mathbf{189,000} \frac{\boldsymbol{ton}}{\boldsymbol{yr}}$$

<u>Step 2</u> – Select and record the appropriate EFs. Table 8-2 lists the EFs for $PM_{2.5}$ as **0.0026 lb/yd^3** for weigh hopper loading and **0.0010 lb/yd^3** for central mix loading.

<u>Step 3</u> – Calculate emissions. $PM_{2.5}$ emissions associated with weigh hopper loading and central mix loading are calculated using the recorded EFs, Equation 8-1, and the information provided as follows:

$$E(Pol) = Q \times EF(Pol)$$

$$\boldsymbol{E(PM_{2.5})_{weigh\ hopper\ loading}} = 0.0026\,\frac{lb}{\cancel{yd^3}} \times \frac{1\,\cancel{yd^3}}{4024\,\cancel{lb}} \times 189{,}000\,\frac{\cancel{ton}}{yr} \times \frac{2000\,\cancel{lb}}{\cancel{ton}} = \boldsymbol{244.23\,\frac{lb}{yr}}$$

$$\boldsymbol{E(PM_{2.5})_{central\ mix\ loading}} = 0.0010\,\frac{lb}{\cancel{yd^3}} \times \frac{1\,\cancel{yd^3}}{4024\,\cancel{lb}} \times 189{,}000\,\frac{\cancel{ton}}{yr} \times \frac{2000\,\cancel{lb}}{\cancel{ton}} = \boldsymbol{93.94\,\frac{lb}{yr}}$$

Step 4 – Sum total PM emissions. Add the $PM_{2.5}$ emissions from both the weight hopper and central mix loading for the total $PM_{2.5}$ emissions.

$$E(PM_{2.5}) = (244.23 + 93.94)\,\frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(PM_{2.5}) = 338.17\,\frac{lb}{yr}}}$$

8.6 References

Section 11.12 – "Concrete Batching," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 2006

9 SITE REMEDIATION (RDL)

- *Point* Source – Remediation System
- *Fugitive* Source – Emissions from Contamination Site

***Site Remediation can potentially be a stationary source if collocated at a major source of HAPs and subject to 40 CFR 63 Subpart GGGGG, which currently (June 2023) applies to less than five DAF installations. Refer to *Air Emissions Guide for DAF Stationary Sources* for additional information.**

9.1 Introduction

Air Force Installations occasionally have sites that are contaminated with hazardous substances because of chemical leaks, spills or prior disposal practices that require site remediation. The Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the Resource Conservation and Recovery Act (RCRA) require the remediation of sites contaminated by hazardous materials that pose a risk to public health or the environment. Additional guidelines and procedures for remediation of these sites are further defined under the National Contingency Plan (NCP).

During CERCLA response actions/RCRA corrective actions, Environmental Restoration Program Managers (ERPMs) must remain cognizant of, and comply with, certain requirements that are promulgated under the authority of other statutes (e.g., Clean Air Act or the Toxic Substances Control Act). Program specific requirements may have a dramatic impact on which remedies may be feasible because of the regulatory and/or technical constraints imposed under other environmental regulatory programs.

CERCLA response actions that are conducted entirely on-site do not require Federal, State, or local permits, but must comply with substantive requirements that are either "applicable" or "relevant and appropriate." Wastes collected using actions of CERCLA that are transferred off-site must comply with the CERCLA Off-site Rule as well as the substantive and administrative requirements. Off-site actions, however, are not governed by the concept of relevance and appropriateness.

During RCRA corrective actions, ERPMs must comply with both substantive and administrative requirements that are applicable to a specific corrective action including the administrative requirement of applying for, obtaining, and operating under an approved permit. These actions, however, need not comply with requirements that are deemed only relevant and appropriate.

9.2 Air Quality Regulatory Requirements

The EPA has promulgated regulations and policies to provide practical approaches which allow flexibility in managing site remediation. Often, regulations applicable to site remediation involve treating, storing, disposing, or re-disposing hazardous waste. Generally, the regulatory approach requires that on-site remedial actions must attain or exceed (or waive in some circumstances) Federal and State Applicable or Relevant and Appropriate Requirements (ARARs) of environmental regulations and policies.

9.2.1 Applicable or Relevant and Appropriate Requirements (ARARs)

When attempting to determine whether specific CAA requirements are potential ARARs and, more specifically, whether they are either "applicable" or "relevant or appropriate" to remediation activities, ERPMs may need to know the following:

- Air quality designation of the site's location (i.e., attainment, nonattainment, unclassified, transport) for each NAAQS,
- Classification of each designated nonattainment area (e.g., marginal, moderate, or serious),
- Whether construction or modification of their stationary source commenced after the date of publication of regulations (or proposed regulations) prescribing a standard of performance that governs such source,
- Required control measures including emissions limitations and emissions offsets, and
- Baseline emission estimates at the site and estimated (i.e., modeled) air pollutant emissions associated with the site investigation activities, construction of remedy, and subsequent operation and maintenance of the remedy. (EPA, 1992a)

9.2.2 ARAR Waivers

Waivers, which by statute apply to on-site CERCLA remedial actions, must be invoked for each ARAR that will not be attained. Because removal actions must comply with ARARs to the extent practicable, waivers are also available for removal actions. Six statutory waivers are codified under 40 CFR 300.430(f)(1)(ii)(C)(1)-(6) and include the following (see also 55 FR8747-50):

- Interim measures,
- Greater risk to health and the environment,
- Technical impracticability from an engineering perspective,
- Equivalent standard of performance,

- Inconsistent application of State standards, and
- Fund balancing.

In addition to statutory waivers, ERPMs may consider the existence of exclusions, exemptions, and variances under other laws because often environmental or technical reasons exist for such provisions. However, even if an exclusion, exemption, or variance provision matches the circumstances at the site, ERPMs should be aware that a requirement may remain relevant and appropriate for other reasons.

Sufficient information, available at the time of Record of Decision (ROD) signature, may indicate the possibility that an ARAR waiver may be invoked at a site (e.g., the remedial investigation/feasibility study (RI/FS) indicates it may be technically impracticable to attain Maximum Contaminant Levels (MCLs) in ground water). ERPMs should then consider including contingency language in the ROD.

9.2.3 Major Source of Hazardous Air Pollutants (HAPs)

Under the 1990 amendments to the CAA, stationary sources of HAPs regulated under 40 CFR Part 61 and categories of sources regulated under 40 CFR Part 63 resulting from CERCLA response activities at a facility may be subject to CAA authority. CAA §112(b)(1) contains a complete list of the 189 HAPs, which include compounds (i.e., any unique substance that contains the named chemical such as cobalt, cyanide, or mercury as part of that chemical's infrastructure) and radionuclides.

Major sources of HAPs are stationary sources, or a group of stationary sources located within a contiguous area and under Department of Defense (DoD) control that emit or have the potential to emit, in the aggregate, 10 tons or more per year of a single HAP or 25 tons or more per year of any combination of HAPs, after emission controls are considered. ERPMs may be required to apply the EPA-developed MACT standards at CERCLA sites with a source category that emits or has the potential to emit HAPs. This is dependent on whether the source qualifies as a major source. For an area source (i.e., any stationary source of HAPs that is not a major source), ERPMs may be able to use Generally Available Control Technology (GACT) or management practices as a substitute for MACT standards.

In 1989, EPA issued a Statement of Policy to guide decision makers on (1) the use of controls for air emissions from air strippers and other vented sources of VOCs used at CERCLA response sites for ground water treatment and (2) the establishment of procedures for implementation. ERPMs responsible for sites that are implementing pump-and treat operations may identify air stripping, during which VOCs in the water are transferred to a vapor phase as an integral component of the remedial alternative. One known side effect of air stripping is the emission of VOCs into the ambient air. At a minimum, the five major types of information that should be generated during the RI/FS are:

- Emission data, including the pollutants expected to be emitted and the rate of emission for each pollutant (e.g., TCE emissions rate from all air strippers at the site),
- Consideration of health risks from the execution of the remedy as well as from the uncontrolled site,
- Control alternatives and their costs,
- Ozone attainment status, and
- Potential air ARARs.

Major stationary sources defined under 40 CFR 70.2 (e.g., sources that emit or have the potential to emit 10 tons/year or more of VOCs in areas classified as severe) are also considered major sources for the criteria pollutant (e.g., ozone). New major stationary sources or major modifications located in any area that cause, or contribute to, a violation of any of the six NAAQS must meet certain criteria (e.g., specific emission standards, LAERs). RCRA corrective action units releasing these pollutants may require approved construction permits (before construction, installation, or modification of the unit) and operating permits, which identify emission rates and limitations, process rates, and maximum operation conditions. Under §121(e) of CERCLA, CERCLA response actions that are conducted entirely on-site will not require permits for actions carried out in compliance with §121 but may require approved emission rates and limitations, process rates, and maximum operation conditions.

9.2.4 National Ambient Air Quality Standards

NAAQS are standards established by the EPA under authority of the CAA that apply to outdoor air throughout the country. NAAQS are not enforceable in and of themselves and are never ARARs. They may, however, constitute To-Be-Considered (TBC) materials under CERCLA actions. It is the emission standards, which are promulgated by the state to attain the NAAQS, that are directly enforceable and are potential ARARs. NAAQS do not apply during RCRA corrective actions, unless legally applicable.

9.2.5 New Source Performance Standards (NSPS)

Under the NSPS program, EPA established nationally uniform standards for major new stationary sources, particularly for industrial source categories. These categories are listed in 40 CFR 60. NSPS are based on Best Demonstrated Technology (BDT), which EPA may define as an emission limit or rate (i.e., a specified number of pounds per hour) or a technological system of continuous emission reduction. At present, the NSPS source categories coincide with only a few of the air pollutant emission sources typically found at

CERCLA sites. Thus, NSPS are not typically considered "applicable" to CERCLA activities. They may be "relevant and appropriate" if the pollutant emitted and the technology employed during remediation are sufficiently similar to the pollutant and source category regulated by NSPS. This is a site-specific determination.

9.2.6 RCRA Subparts AA, BB, and CC

Air emission standards under RCRA (Subparts AA, BB, and CC of 40 CFR Parts 264 and 265) may be applicable to CERCLA response actions/RCRA corrective actions. Air emission standards of Subpart AA concern process vents associated with specific operations (i.e., air or steam stripping, solvent extraction, thin-film evaporation, fractionation, or distillation). Standards of Subpart BB concern equipment (e.g., pumps, valves, pressure relief devices). These standards will be "applicable" during ground water treatment provided:

- For subpart AA, the contaminated water managed in a specified operation has an annual average total organic concentration of 10 ppmw or greater (DOE 1993a), or
- For Subpart BB, the equipment contains or contacts hazardous wastes with organic concentrations of at least 10 percent by weight (DOE 1993b), and
- The contaminated ground water qualifies as hazardous waste, and
- The contaminated ground water is being managed at a RCRA Treatment, Storage, and Disposal Facility (TSDF) or 90-day generator.

Although not pertinent to RCRA corrective actions, Subparts AA and BB control requirements may considered "relevant and appropriate" to on-site CERCLA actions that use one of the previously discussed technologies when managing wastes that are not otherwise subject to Subparts AA or BB (e.g., wastes with organic concentration of less than 10 ppmw/10 percent by weight, organics from nonhazardous waste) (55FR 25458) (EPA 1992).

Subpart CC standards govern the management of organics in containers, tanks, surface impoundments, and miscellaneous units (when appropriate). These standards apply to TSDFs and 90-day generators accumulating waste on-site in permit-exempt tanks and containers.

9.3 Remediation Technologies

Typically, contaminants on Air Force Installations consist of either organic solvents (e.g., perchloroethylene, trichloroethylene) or petroleum products (e.g., jet or diesel fuels, etc.). Identification, investigation, and cleanup of these contaminants on active Air Force and Base Realignment and Closure (BRAC) installations falls under the jurisdiction of the DoD's Environmental Restoration Program (ERP). The Air Force Civil Engineer Center (AFCEC) also provides additional support for restoration programs through its Environmental Restoration Division (CZR).

There are a variety of technologies available to remediate contaminants from soil and groundwater. The contaminant(s) targeted for removal dictate the specific technology selected for the remediation process, though two or more remediation methods are often used in conjunction. Some of these technologies involve the transfer of the existing contaminant from the vadose (i.e., unsaturated) and/or phreatic (i.e., saturated) soil zones into an air stream, which may either be vented directly into the atmosphere or through a control device (e.g., biofiltrator, carbon adsorber, catalytic or thermal oxidizer, etc.). Air emissions from the use of these technologies must then be calculated for air emission inventory purposes. Site remediation is performed only on a temporary basis and only in response to the clean-up of sites where hazardous material was released.

Emissions of concern from site remediation projects are VOCs from organic contaminants, other criteria pollutants, HAPs, and GHGs, depending upon the contaminant in question. The contaminant involved at each remediation site (<u>including any intermediate or final degradation products of the initial contaminant</u>) must be known to calculate emissions. Emissions are calculated following a simple mass balance approach, as any contaminant not captured by control devices or still incorporated in the soil or groundwater at the remediation site is assumed to have vented directly into the atmosphere. Air emissions at sites that are being remediated are both point and fugitive. **The pollutants emitted from the contamination site are fugitive while those released into the atmosphere by the remediation equipment are point sources.**

9.4 Emission Sources

The Site Remediation NESHAP lists three groups of affected sources: Process Vents, Remediation Material Management Units, and Equipment Leaks. The three groups are described in the following sections:

9.4.1 Process Vents

Process Vents include the entire group of process vents associated with the in-situ and ex-situ remediation process to remove, destroy, degrade, transform, or immobilize hazardous substances in remediation material. The two most common technologies used in site remediation that result in air emissions through process vents are Soil Vapor Extraction (SVE) and Air Stripping (AS). In some cases, any air emissions resulting from site remediation technologies may be considered negligible and may not need to be quantified. Before making that determination, the appropriate local/state regulatory board should be contacted. A simple control volume detailing the emissions from site remediation is provided in Figure 9-1.

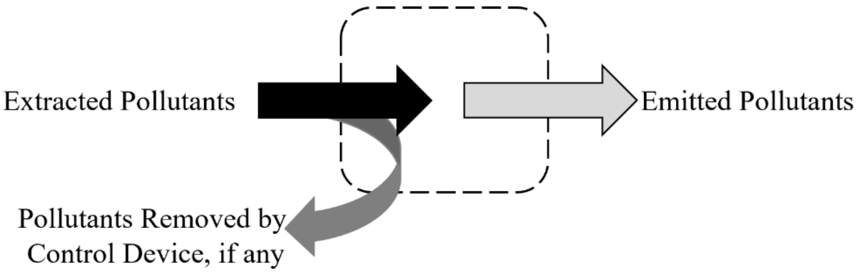

Figure 9-1. Simple Control Volume for Emissions from Site Remediation

The calculation of emissions from site remediation requires testing and monitoring to determine pollutant concentration, which, as described in the following sections, may be used in conjunction with the flow rate to determine air emissions. For this reason, there are no emission factors that have been developed that are applicable to the direct emissions of pollutants at remediation sites. However, site remediation often involves a control device, such as a flare, to combust exhaust gas. Whenever a combustion source is used, the emissions generated must also be addressed. The method for calculation is not addressed here, but in the "External Combustion" section of the *Air Emissions Guide for Air Force Stationary Sources*.

Emissions from SVE and AS remediation technologies are calculated in a similar, though slightly different manner. Emissions from these are a function of the airflow or water pumping rate, the concentration of the pollutant, and the control efficiency of the control device if present. Air emissions calculations from SVE and AS are described below.

9.4.1.1 Soil Vapor Extraction (SVE)

SVE is a remediation technology used to remove pollutants from soil within the vadose zone. One or more extraction wells are placed near the contaminant plume. These wells introduce a pressure gradient, resulting in air flow towards an extraction well. Any existing pollutants are transferred into the passing air stream and the resulting contaminant-laden air stream is then either vented directly into the atmosphere or to a control device. The concentration of the pollutant is measured by a Flame Ionization Detector (FID) or Photo Ionization Detector (PID) device from that point source. A FID works by detecting the ions created by the combustion of gas, which flows through a flame. This device is sensitive to hydrocarbons, however the presence of atoms that are non-hydrocarbons may reduce the detector's response. A PID contains an ultraviolet (UV) lamp that ionizes the incoming gas. The ions are driven to a collector electrode that measures the resultant current, which directly correlates to the concentration of the analyte in the sample. Note that it may be necessary to apply a correction (or scaling) factor to the reading provided by the PID. The correction factor is a measure of the sensitivity of the photoionization detector to a specific gas. Some PIDs may provide the value of the target chemical after it has been corrected with the scaling factor, but this may need to be performed manually for an accurate measure of the chemical concentration.

Air emissions from SVE are calculated per extraction well. In general, technologies resulting in air emissions will have a point source of the pollutant that is either directly discharged into the atmosphere or through a control device. It is preferable to sample SVE systems at the point where pollutants are released from the process vent into the atmosphere. Alternatively, the system may be sampled prior to the air stream entering a control device.

Emissions from each extraction well should be calculated individually and summed for the total emissions per chemical species. The pollutant emissions from SVE systems may be calculated as follows:

$$\boldsymbol{E(Pol) = Q \times C(Pol) \times MW(Pol) \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 9-1

Where,

E(Pol) = Emissions of a pollutant (lb/yr)
Q = Flow rate of the extracted air (ft^3/min)
C(Pol) = Concentration of the pollutant in the extracted air (ppmv)
MW(Pol) = Molecular weight of the pollutant (lb/lb-mole)
1.581×10^{-7} = Equation constant [(lb-mole min)/(ppmv ft^3 hr)]
t = Time in operation during the year (hr/yr)
CE = Control efficiency of the control device, if present (%)
100 = Factor converting percent to a fraction (%)

The equation constant was derived as follows:

$$\frac{1}{10^6\ ppmv} \times \frac{60\ min}{1\ hr} \times \frac{1\ lb\text{−}mole}{379.5\ ft^3} = 1.581 \times 10^{-7}\ \frac{lb\text{−}mole \cdot min}{ppmv \cdot ft^3 \cdot hr}$$

A detailed control volume of emissions from soil vapor extraction is provided in Figure 9-2.

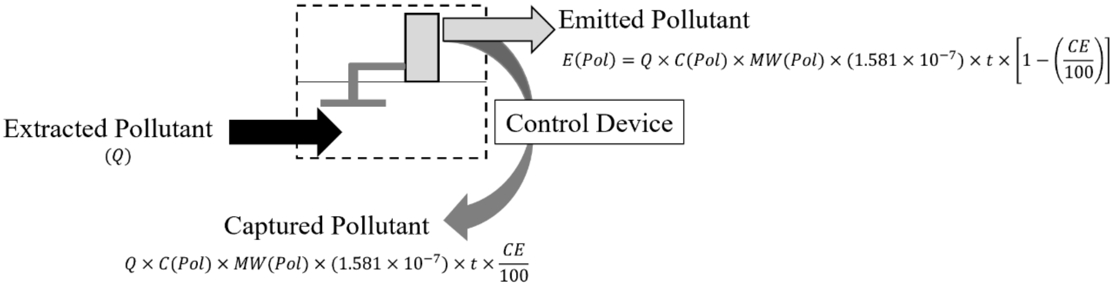

Figure 9-2. Soil Vapor Extraction Control Volume

9.4.1.2 Air Stripping (AS)

Air stripping is often utilized concurrently with SVE methods of remediation for contaminated ground or surface water. Once the contaminated water is pumped to the treatment site, it is introduced into an air stripping or aeration tank, which is filled with a packing material that impedes the flow of the water. While the water is pumped downwards, air is injected from the bottom of the tank and flows counter to the flow of the water pumped into the tank. The packing material increases the exposure time between the air and water. The target contaminant is volatilized into the air stream, which flows out the top of the tank. The air stream may either be vented directly into the atmosphere or to a control device.

As with SVE systems, the preferred sampling point is where pollutants are released from the process vent into the atmosphere. An alternate sampling point would be prior to the aeration tank. If the air stripping system is sampled at the preferred location, Equation 9-1 is used to calculate pollutant emissions from the system.

To calculate emissions from air strippers based on groundwater input at the alternate sampling point, the pollutant concentration in the groundwater must first be measured. Air emissions resulting from air strippers are calculated as follows:

$$\boldsymbol{E(Pol) = Q \times C(Pol) \times \frac{RE}{100} \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]}$$

Equation 9-2

Where,

Q = Groundwater pumping rate (gal/min)
C(Pol) = Concentration of the pollutant in the groundwater (mg/L)
RE = Removal efficiency of the air stripper (%)
100 = Factor converting percent to a fraction (%)
$5.042\text{x}10^{-4}$ = Equation constant [(lb L min)/(mg gal hr)]

The equation constant was derived as follows:

$$\frac{lb}{10^6\,mg} \times \frac{60\,min}{1\,hr} \times \frac{1000\,L}{261.8\,gal} = 5.042 \times 10^{-4}\,\frac{lb\cdot L\cdot min}{mg\cdot gal\cdot hr}$$

A detailed control volume of emissions from air stripping is provided in Figure 9-3

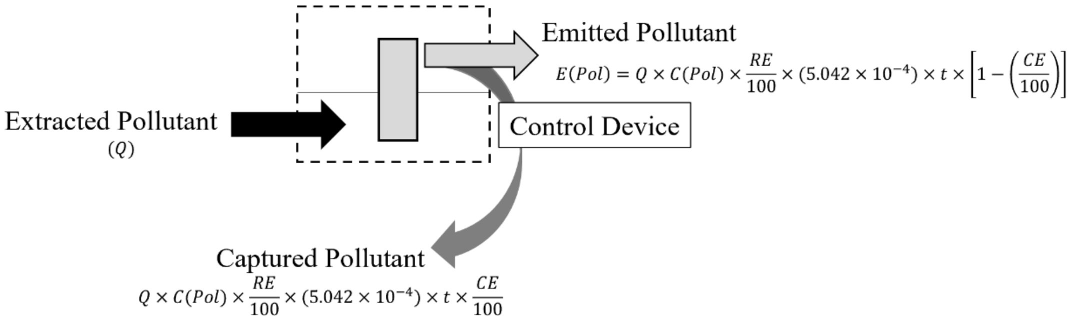

Figure 9-3. Air Stripping Control Volume

9.4.2 Remediation Material Management Units

Remediation material management units are devices used to hold and manage remediation materials. A tank or container equipped with a vent that serves as a process vent is not a remediation material management unit. These devices include but are not limited to tanks, surface impoundments, oil-water separators, and organic-water separators. Methods for calculating pollutant emissions from remediation material management units can be found in the “Storage Tanks” section of the *Air Emissions Guide for Air Force Stationary Sources*.

9.4.3 Equipment Leaks

Equipment leaks are leaks from the entire group of equipment components associated with a remediation site. These include but are not limited to pumps, valves, and pipe connections. Methods for calculating pollutant emissions from equipment leaks can be found in the “Spills and Releases” section of this Guide.

9.5 Information Resources

All site restoration activities on active Air Force Installations are overseen by Base Environmental (CEV), which may be contacted for any information required to calculate air emissions. Additionally, the contractor operating the remediation system(s) may also be contacted to obtain any required information.

9.6 Example Problems

9.6.1 Problem #1 (Soil Vapor Extraction)

A DAF Base is looking to calculate air emissions from a remediation site located on base. SVE was used to remove perchloroethylene (PCE) from one extraction well at this location. The SVE process was in operation for approximately 1200 hours with an air flow rate of 120 ft^3/min and an average measured PCE concentration of 215 ppmv. The extracted air was vented to a catalytic oxidizer, with a stated control efficiency of 97%, prior to being released to the atmosphere. Given that the molecular weight of PCE is 165.8 lb/lb-mole, calculate the emissions of PCE from this process at this site.

Step 1 – **Calculate emissions.** All the data required for emissions calculation is provided in the problem statement. Using this data and Equation 9-1, emissions may be calculated as follows:

$$E(Pol) = Q \times C(Pol) \times MW(Pol) \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$E(PCE) = 120\frac{ft^3}{min} \times 215\,ppmv \times 165.8\frac{lb}{lb\text{−}mole} \times (1.581 \times 10^{-7})\frac{lb\text{−}mole\ min}{ft^3\ ppmv\ hr} \times 1200\frac{hr}{yr} \times \left[1 - \left(\frac{97\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E(PCE) = 120\frac{ft^3}{min} \times 215\,ppmv \times 165.8\frac{lb}{lb\text{−}mole} \times (1.581 \times 10^{-7})\frac{lb\text{−}mole\ min}{ft^3\ ppmv\ hr} \times 1200\frac{hr}{yr} \times [1 - 0.97]$$

$$E(PCE) = 120\frac{ft^3}{min} \times 215\,ppmv \times 165.8\frac{lb}{lb\text{−}mole} \times (1.581 \times 10^{-7})\frac{lb\text{−}mole\ min}{ft^3\ ppmv\ hr} \times 1200\frac{hr}{yr} \times [0.03]$$

$$E(PCE) = 4{,}277{,}64\frac{\cancel{ft^3\ ppmv}\ lb}{\cancel{\text{min}}\,\cancel{lb\text{−}mole}} \times (1.581 \times 10^{-7})\frac{\cancel{lb\text{−}mole\ min}}{\cancel{ft^3\ ppmv\ hr}} \times 1200\frac{hr}{yr} \times [0.03]$$

$$E(PCE) = 0.67629\frac{lb}{\cancel{hr}} \times 1200\frac{\cancel{hr}}{yr} \times [0.03]$$

$$E(PCE) = 811.5539\frac{lb}{yr} \times [0.03]$$

$$\boxed{\boldsymbol{E(PCE) = 24.3\frac{lb}{yr}}}$$

9.6.2 Problem #2 (Air Stripping)

In addition to the emissions resulting from the SVE site on base, the same DAF Base is also concerned with emissions at an alternate site where JP-8 was removed from groundwater. This operation was run for about 1120 hours and pumped at an average rate of 45 gal/min. Site testing indicated that the average concentration of VOCs in the groundwater was approximately 160 mg/L. Given that the air stripper removal efficiency for this process is 95% and no control devices are used, calculate the total VOCs emitted into the atmosphere.

Step 1 – **Calculate emissions.** Using Equation 9-2, VOC emissions are calculated as follows:

$$E(Pol) = Q \times C(Pol) \times \frac{RE}{100} \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$E(VOC) = 45\,\frac{gal}{min} \times 160\,\frac{mg}{L} \times \frac{95\cancel{\%}}{100\cancel{\%}} \times (5.042 \times 10^{-4})\,\frac{lb\;L\;min}{mg\;gal\;hr} \times 1120\,\frac{hr}{yr} \times \left[1 - \left(\frac{0\cancel{\%}}{100\cancel{\%}}\right)\right]$$

$$E(VOC) = 45\,\frac{gal}{min} \times 160\,\frac{mg}{L} \times 0.95 \times (5.042 \times 10^{-4})\,\frac{lb\;L\;min}{mg\;gal\;hr} \times 1120\,\frac{hr}{yr} \times [1]$$

$$E(VOC) = 6840\,\frac{\cancel{gal}\;\cancel{mg}}{\cancel{min}\;\cancel{L}} \times (5.042 \times 10^{-4})\,\frac{lb\;\cancel{L}\;\cancel{min}}{\cancel{mg}\;\cancel{gal}\;hr} \times 1120\,\frac{hr}{yr} \times [1]$$

$$E(VOC) = 3.4487\,\frac{lb}{\cancel{hr}} \times 1120\,\frac{\cancel{hr}}{yr} \times [1]$$

$$\boxed{\boldsymbol{E(VOC) = 3862.5\,\frac{lb}{yr}}}$$

9.7 References

EPA, 1992a. ARARs Fact Sheet: Compliance with the Clean Air Act and Associated Air Quality Requirements, OSWER Dir. 9234.2-22FS, Office of Emergency and Remedial Response, Washington D.C.

DOE, 1993a. RCRA Air Emission Standards for Hazardous Waste Treatment, Storage, and Disposal Facility (TSDF) Process Vents, Information Brief, EH-231-020/0193, Office of Environmental Guidance, Washington D.C.

DOE, 1993b. RCRA Air Emission Standards for Hazardous Waste Treatment, Storage, and Disposal Facility (TSDF) Equipment Leaks, Information Brief, EH-231-019/0193, U.S. Department of Energy, Office of Environmental Guidance, Washington, D.C.

EPA, 1992. Seminar Publication: Organic Air Emissions from Waste Management Facilities, EPA/625/R-92/003, Office of Air Quality Planning and Standards, Research Triangle Park, N.C

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10 LAND USE CHANGE

- *Carbon Dioxide Sequestration*

10.1 Introduction

DoD Directive 4715.21, Climate Change Adaptation and Resilience establishes a new policy to assess and manage risks associated with the global impacts of GHGs (climate change) and ensures that the impacts are incorporated into all aspects of military planning. The policy states that DoD must be able to adapt current and future operations to address the impacts of climate change to maintain an effective and efficient U.S. military. Additionally, the CEQ recommends assessment of potential climate change impacts when performing National Environmental Policy Act assessments.

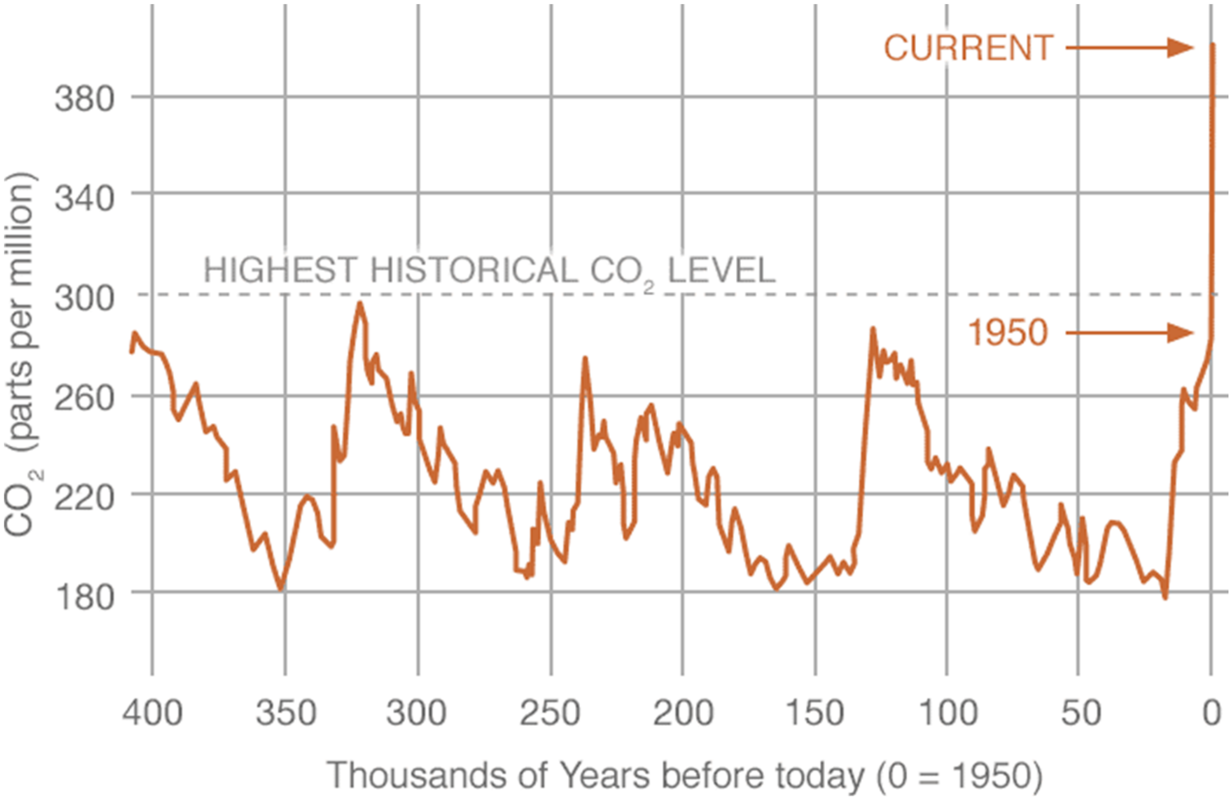
In addition to the criteria pollutants, the EPA has begun to focus attention on GHGs because they trap heat in the earth's atmosphere, increasing global temperatures. Increases in global temperatures affect rainfall patterns and surface temperatures, which leads to climate change. One of the principal GHGs is CO_2. There are many sources of CO_2 emissions, which primarily include the burning of fossil fuels. To stem the consequences of CO_2 emissions, sequestering CO_2 has become an important topic.

Sequestration is the environment's natural ability to remove and store air pollutants such as CO_2. Assessing CO_2 sequestration changes associated with an action has become a surrogate for assessing potential impacts of an action on the global impacts of GHGs (climate change). This chapter addresses quantifying CO_2 sequestration, or the loss of sequestration (sequestration forfeiture) associated with changing land use.

10.2 Background Information

CO_2 is an important heat trapping gas, which is released through human activities such as deforestation and burning fossil fuels, as well as natural processes such as respiration and volcanic eruptions. The carbon found in atmospheric CO_2 is just a tiny fraction of earth's total carbon reserves. Carbon is also found in rocks, oceans, fossil fuel deposits, and all living things. The movement of carbon atoms between these reservoirs is known as the carbon cycle. Carbon leaves the atmosphere when photosynthesizing organisms such as plants, algae, and some kinds of bacteria pull it out of the air and combine it with water to form carbohydrates. It gets returned to the atmosphere as CO_2 when humans and other animals breathe it out, or when plants die and decompose. Sometimes, instead of rotting and releasing their carbon back into the atmosphere, photosynthesizers get buried deep underground, locking their carbon away in the earth for millions of years.

Over time, this balance of intake and emission has kept the amount of CO_2 in the atmosphere relatively cyclic with the maximum CO_2 level below 300 ppm. However, the amount of CO_2 in the atmosphere has increased steadily since the beginning of the Industrial Revolution, with CO_2 concentrations rising especially sharply in the latter half of the 20th century. Figure 10-1. Carbon Dioxide Level Over Time, shows CO_2 levels during the last three glacial cycles, as reconstructed from ice cores. Since 1950 there has been a dramatic increase in CO_2 levels well beyond the 300 ppm of the past natural cycles which has been causally linked to human activities and global impacts of GHGs (climate change). Human activities associated with changes to land use may directly impact local air quality by reducing the environment's natural ability to sequester (remove and store) air pollutants.



SOURCE: https://climate.nasa.gov/system/charts/15_co2_left_061316.gif (Data source: Reconstruction from ice cores. Credit: NOAA).

Figure 10-1. Carbon Dioxide Level Over Time

Solar radiation and the presence of GHGs in Earth's atmosphere play a large role in the temperature of the planet. Solar radiation passes through the atmosphere and warms Earth's surface. Naturally occurring GHGs, such as CO_2, CH_4 and even water vapor (H_2O) creates an insulating layer in the atmosphere, which helps prevent the heat from escaping Earth. This makes the Earth warm enough to sustain life.

This guidance contains methodologies which may be used to calculate the sequestration or forfeiture (loss) of sequestration of CO_2 that occurs when the use of a parcel of land is changed for NEPA reviews. An example of a land use change is when a parcel of grassland becomes a forestland through the planting of trees.

10.3 Calculation Methodology

The CEQ and DoD guidance falls short of recommending a methodology for agencies to use when addressing land use change in NEPA reviews. In this regard, agencies are tasked to determine the best methodology that fits their needs. To quantify the effect of land use change on GHGs, an appropriate methodology would consider the amount of CO_2 that is captured from the atmosphere and stored as carbon in plant material during photosynthesis. Additionally, an appropriate methodology would consider all carbon pools, such as above ground plant material, below ground plant material, and soil. Furthermore, different types of land (forest, grassland, wetlands, and agriculture) store carbon at different rates depending on climatic conditions and vegetation type, therefore an appropriate methodology would consider climate and vegetation type as well. The U.S. Geological Survey (USGS) has published three reports that assess the carbon fluxes (changes) among different land types in different regions of the United States. To date, this USGS data is the most appropriate to use for calculating the carbon or CO_2 flux of different land use changes.

10.3.1 USGS Methodology Background

In 2007, Congress directed the Department of the Interior to develop a methodology to assess the amount of carbon stored in ecosystems, the capacity of ecosystems to sequester carbon, and the rate of GHG fluxes in and out of the ecosystems. In response to that directive, the USGS has produced three reports to fulfill the requirements of section 712 of the Energy Independence and Security Act (EISA) of 2007. These reports divided the continental United States into three regions. Western Region, Eastern Region, and Great Plains Region.

For these regional assessments, three biogeochemical models were run in an ensemble fashion on the General Ensemble Biogeochemical Modeling System (GEMS) platform. These biogeochemical models were used to simulate ecosystem biogeochemical cycles and estimate carbon flux values. The biogeochemical models used are the Century version 4.0, the Erosion Deposition Carbon Model (EDCM), and the Land Greenhouse Gas Accounting Tool (LGAT). Included in these USGS reports is an assessment of the amount of carbon dioxide sequestered by various land uses, such as forest land, grassland, wetland, and agriculture for each region. It is these values that serve as the basis for this methodology.

10.3.2 Sequestration Factors

Sequestration factors were derived based on the USGS regional reports for use when calculating sequestration or sequestration forfeiture from land use change (see Table 10-1. Sequestration Factors for Various Regions and Land Types). These factors represent how much CO_2 a type of land scenario sequesters per year in each specific region. Information regarding Alaska is in development. These regions are shown in Figure 10-2. Regional Map for Land Use Change Sequestration Factors.

Table 10-1. Sequestration Factors for Various Regions and Land Types

Region	Land Type	Annual CO_2 Sequestration (lb CO_2/acre)
Great Plains Average [a]	Forests	6297.3
	Wetlands	1704.4
	Agricultural Lands	615.0
	Grasslands/shrublands	438.4
	Impervious Surfaces (e.g., buildings, parking lots, etc.)	0.0
Western Average [b]	Forests	2355.4
	Wetlands	NA
	Agricultural Lands	1243.1
	Grasslands/shrublands	523.4
	Impervious Surfaces (e.g., buildings, parking lots, etc.)	0.0
Eastern Average [c]	Forests	5070.6
	Wetlands	4318.1
	Agricultural Lands	392.6
	Grasslands/shrublands	1341.2
	Impervious Surfaces (e.g., buildings, parking lots, etc.)	0.0

a. Zhu, Zhiliang, ed., Bouchard, Michelle, Butman, David, Hawbaker, Todd, Li, Zhengpeng, Liu, Jinxun, Liu, Shuguang, McDonald, Cory, Reker, Ryan, Sayler, Kristi, Sleeter, Benjamin, Sohl, Terry, Stackpoole, Sarah, Wein, Anne, and Zhu, Zhiliang, 2011, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in the Great Plains Region of the United States: U.S. Geological Survey Professional Paper 1787, 28 p. (Also available at http://pubs.usgs.gov/pp/1787/.).

b. SOURCE: Zhu, Zhiliang, and Reed, B. C., eds., 2012, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1797, 192 p. (Also available at http://pubs.usgs.gov/pp/1797/.).

c. SOURCE: Zhu, Zhiliang, and Reed, B. C., eds., 2014, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1804, 204 p., http://dx.doi.org/10.3133/pp1804.

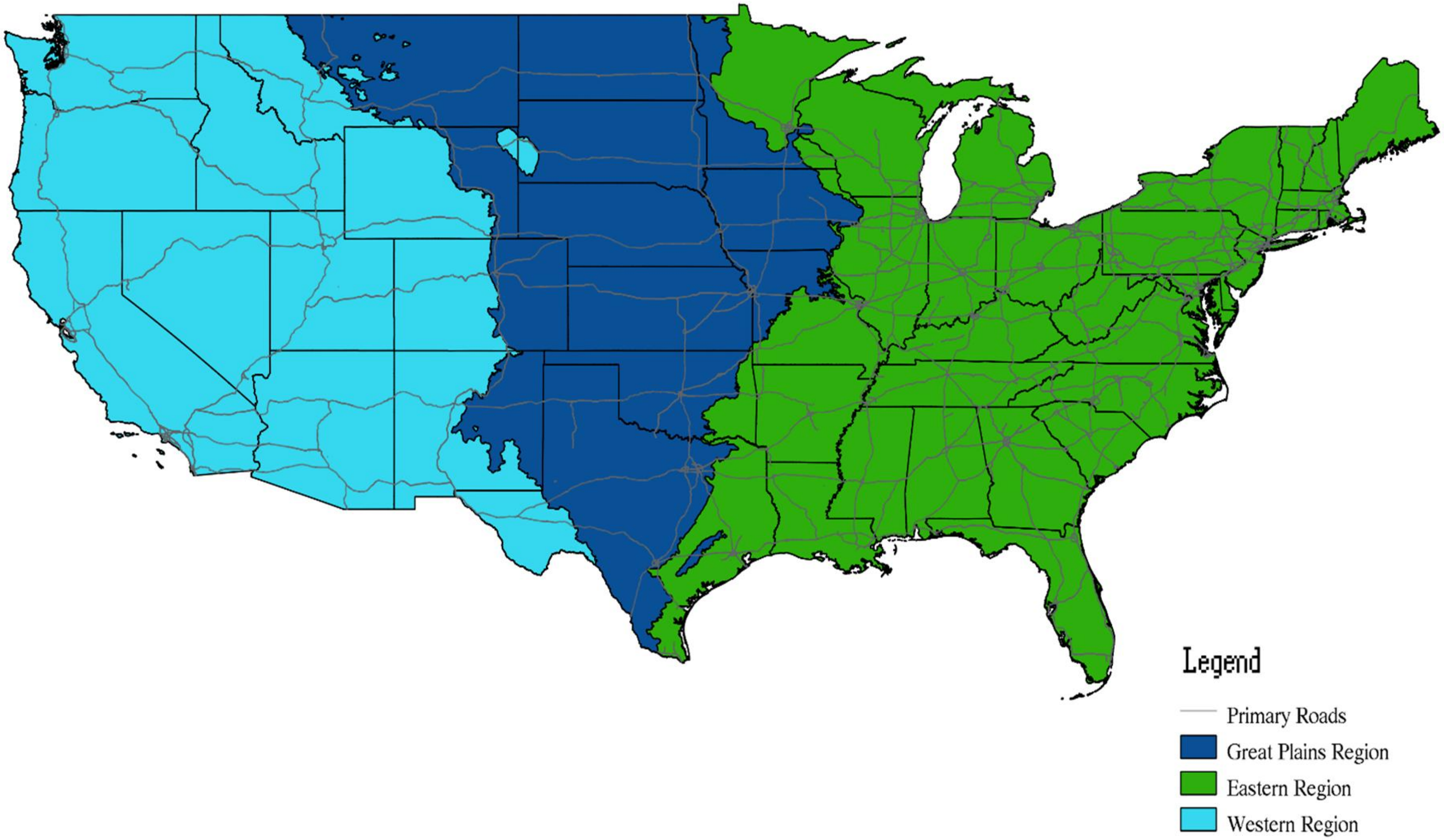


Figure 10-2. Regional Map for Land Use Change Sequestration Factors

10.3.3 Calculating Sequestration

The USGS methodology can be used to calculate the carbon dioxide sequestration of a land use change. This methodology is designed to be used for instances when land is being changed from one use to another, such as a grassland being converted into a forestland. Sequestration, both gains and losses from changing land use, can be calculated using Equation 10-1. Positive values for sequestration change indicate that the land use change has increased the sequestration of the land. Negative values indicate that the land use change resulted in a decrease of sequestration, meaning less pollutants such as CO_2 are removed and stored. Use Figure 10-2 to identify the ecoregion that the land use change is occurring in and then use the sequestration factors from Table 10-1 as inputs into Equation 10-1 to calculate the change in sequestration.

$$\Delta \boldsymbol{S} = \left(\boldsymbol{A_f} \times \boldsymbol{SF_f}\right) - \left(\boldsymbol{A_i} \times \boldsymbol{SF_i}\right)$$

Equation 10-1

Where,

ΔS = Sequestration change (lb CO_2/yr)
A_f = Area of land after land use change (acre)
SF_f = Sequestration factor of land type after change (lb CO_2/acre-yr)
A_i = Area of land before land use change (acre)
SF_i = Sequestration factor of land type before change (lb CO_2/acre-yr)

10.4 Example Problems

10.4.1 Problem #1 (Increase in Sequestration)

A DAF Base in Florida is considering converting 30 acres of grassland into forestland. Determine the sequestration change.

<u>Step 1</u> – Determine the region the land use change is occurring. Since the DAF Base is in Florida, it is in the Eastern Region.

<u>Step 2</u> – Select the appropriate sequestration factors. For the Eastern Region, the sequestration factor for grassland and forestland (as given in Table 10-1) are **1341.2 lb CO_2/acre-year** and **5070.6 lb CO_2/acre-year,** respectively.

<u>Step 3</u> – Calculate the sequestration change. Use the sequestration factors from Step 2 and Equation 10-1 to calculate this value.

$$\Delta S = \left(A_f \times SF_f\right) - \left(A_i \times SF_i\right)$$

$$\Delta S = \left(30\ \cancel{acres} \times 5070.6 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right) - \left(30\ \cancel{acres} \times 1341.2 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right)$$

$$\Delta S = \left(152{,}118 \frac{lb\ CO_2}{yr}\right) - \left(40{,}236 \frac{lb\ CO_2}{yr}\right)$$

$$\boxed{\Delta \boldsymbol{S} = \mathbf{111,882} \frac{\boldsymbol{lb\ CO_2}}{\boldsymbol{yr}}}$$

10.4.2 Problem #2 (Decrease in sequestration/forfeiture)

A DAF Base in Utah has decided to clear 25 acres of forestland and convert this to grassland. Determine the change in sequestration.

<u>Step 1</u> – Determine the region the land use change is occurring. Since the DAF Base is in Utah, it is in the Western Region.

<u>Step 2</u> – Select the appropriate sequestration factors. For the Western Region, the sequestration factor for grassland and forestland (as given in Table 10-1) are **523.4 lb CO_2/acre-year** and **2355.4 lb CO_2/acre-year,** respectively.

<u>Step 3</u> - Calculate the sequestration change. Use the sequestration factors from Step 2 and Equation 10-1 to calculate this value.

$$\Delta S = \left(A_f \times SF_f\right) - (A_i \times SF_i)$$

$$\Delta S = \left(25\ \cancel{acres} \times 523.4 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right) - \left(25\ \cancel{acres} \times 2355.4 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right)$$

$$\Delta S = \left(13{,}085 \frac{lb\ CO_2}{yr}\right) - \left(58{,}885 \frac{lb\ CO_2}{yr}\right)$$

$$\boxed{\Delta \boldsymbol{S} = \mathbf{-45,800} \frac{\boldsymbol{lb\ CO_2}}{\boldsymbol{yr}}}$$

10.4.3 Problem #3 (Decrease in sequestration/forfeiture)

A DAF Base in Utah has decided to clear 25 acres of forestland and convert this to into a 5-acre office building and a 15-acre parking lot with the remaining 5 acres being grass. Determine the change in sequestration.

<u>Step 1</u> – Determine the region the land use change is occurring. Since the DAF Base is in Utah, it is in the Western Region.

<u>Step 2</u> – Select the appropriate sequestration factors. For the Western Region, the sequestration factor for grassland and forestland (as given Table 10-1) are **523.4 lb CO_2/acre-**

year and **2355.4 lb CO2/acre-year,** respectively. The building and parking lot (20 acres total) are impervious surfaces; therefore, the sequestration factor is **0.0 lb/CO2/acre-year.**

Step 3 - Calculate the sequestration change. Use the sequestration factors from Step 2 and Equation 10-1 to calculate this value.

$$\Delta S = \left(A_f \times SF_f\right) - \left(A_i \times SF_i\right)$$

$$\Delta S = \left[\left(5\ \cancel{acres} \times 523.4 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right) + \left(20\ \cancel{acres} \times 0.0 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right)\right] - \left(25\ \cancel{acres} \times 2355.4 \frac{lb\ CO_2}{\cancel{acre}\ yr}\right)$$

$$\Delta S = \left(2{,}617 \frac{lb\ CO_2}{yr}\right) - \left(58{,}885 \frac{lb\ CO_2}{yr}\right)$$

$$\boxed{\boldsymbol{\Delta S = -56{,}268 \frac{lb\ CO_2}{yr}}}$$

10.5 References

CEQ 2016. Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews, Council on Environmental Quality, 81 FR 51866

Zhu, Zhiliang, ed., Bouchard, Michelle, Butman, David, Hawbaker, Todd, Li, Zhengpeng, Liu, Jinxun, Liu, Shuguang, McDonald, Cory, Reker, Ryan, Sayler, Kristi, Sleeter, Benjamin, Sohl, Terry, Stackpoole, Sarah, Wein, Anne, and Zhu, Zhiliang, 2011, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in the Great Plains Region of the United States: U.S. Geological Survey Professional Paper 1787, 28 p. (Also available at http://pubs.usgs.gov/pp/1787/.)

Zhu, Zhiliang, and Reed, B. C., eds., 2012, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1797, 192 p. (Also available at http://pubs.usgs.gov/pp/1797/.)

Zhu, Zhiliang, and Reed, B. C., eds., 2014, Baseline and Projected Future Carbon Storage and Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1804, 204 p., http://dx.doi.org/10.3133/pp1804

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11 WILDFIRES AND PRESCRIBED BURNING

- *Fugitive* Source

11.1 Introduction

Wildfires and prescribed burns are large combustions of **forest, grassland, brushland, or land sown to crops. Forest fire, brush fire, etc., are often used to describe specific types of wildfires and prescribed burns; their usage varies according to the characteristics of the fire and the region in which it occurs.**

A wildfire is a large-scale natural combustion process that consumes various ages, sizes, and types of flora growing outdoors in a geographical area. Consequently, wildfires are potential sources of large amounts of air pollutants. Emissions from wildfires may travel large distances and contribute to the release of over 10 tons/km^2 of CO_2 annually in the United States (Liu 2005).

Prescribed burning is a land treatment, used under controlled conditions, to accomplish natural resource management objectives. It is one of several land treatments, used individually or in combination, including chemical and mechanical methods. Prescribed fires are conducted within the limits of a fire plan and prescription that describes both the acceptable range of weather, moisture, fuel, and fire behavior parameters, and the ignition method to achieve the desired effects. Prescribed fire is a cost-effective and ecologically sound tool for forest, range, and wetland management. Its use reduces the potential for destructive wildfires and thus maintains long-term air quality. Also, the practice removes logging residues, controls insects and disease, improves wildlife habitat and forage production, increases water yield, maintains natural succession of plant communities, and reduces the need for pesticides and herbicides. The major air pollutant of concern is the smoke produced.

Wildfires and prescribed burn operations result in the fugitive emissions of criteria pollutants and greenhouse gases. A simple control volume describing emissions resulting from wildfires is provided in Figure 11-1

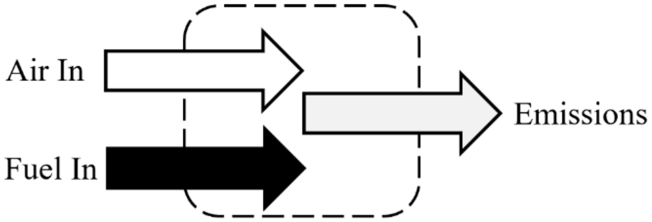


Figure 11-1. Simplified Wildfire & Prescribed Burning Control Volume

11.1.1 Fuel Loading

Both fuel type (composition) and fuel loading on the fire process cannot be overemphasized in estimating emissions from wildfires and prescribed burns. Fuel materials typically include downed trees, fallen branches, decayed matter on the forest floor (duff), small trees, shrubs, and grasses. Tree crowns (branch wood and foliage) can also be burned in wildfires and prescribed fires. The fuel consumption in a fire will depend not only on the total pre-burn fuel loading, but also on the relative composition of the available fuel (amounts of the different fuel types), and on the fuel condition.

There are several methods available to estimate fuel loadings and characteristics; however, the most accurate method is to measure the fuel loading. The Forest Service has developed guidelines for measuring the amount of fuel materials. The line intersect method has been used to develop information on fuel loading and characteristics in advance of a prescribed burn. In this method, a surveyor walks a line through the forest, measuring each downed log that is intersected, and gathering information on other debris and fuel material on the forest floor. Piles are measured, and samples of brush may be clipped and weighed. Unfortunately, these methods are very resource intensive for a regional scale inventory. In addition, they must be used before the fire occurs. (Brown 1974 and Hardy 1996)

For the sake of conformity and convenience, default estimated fuel loadings anticipated for the vegetation in the U. S. Forest Service Regions are presented in Table 11-1; however, site-specific fuel loading data is always preferred. It is strongly urged conduct site-specific fuel loading measurements or to contact that state’s federal land management agencies and state forestry agencies that conduct prescribed burning to obtain the best information on such activities.

11.1.2 Forest Regions

The U.S. Forest Service has established nine Forest Service Regions; numbered 1 through 10 (Region 7 was eliminated in 1965 when the current Eastern Region was created from the former Eastern and North Central regions). These regions are broad geographic areas, usually including several states, encompassing 155 National Forests and 20 National Grasslands. These lands include a vast treasure of diverse landscapes, ecosystems, fauna, and flora. The Air Force further divides two Forest Service Regions (Regions 9 and 10) into subregions based on geographical areas and forest species (see Figure 11-2):

Region 1, Northern Region: The Northern Forest Service Region is within the Rocky Mountain Geographic Area of the U.S. which includes Montana, northern Idaho, North Dakota, northwestern South Dakota, northeastern Washington, and northwestern Wyoming.

Region 2, Rocky Mountain Region: The Rocky Mountain Forest Service Region is within the Rocky Mountain Geographic Area of the U.S. which includes Colorado, Nebraska, Kansas, most of Wyoming and most of South Dakota.

Region 3, Southwestern Region: The Southwestern Forest Service Region is within the Rocky Mountain Geographic Area of the U.S. which includes Arizona and New Mexico.

Region 4, Intermountain Region: The Intermountain Forest Service Region is within the Rocky Mountain Geographic Area of the U.S. which includes primarily southern Idaho, Nevada, Utah, and western Wyoming.

Region 5, Pacific Southwest Region: The Pacific Southwest Forest Service Region is within the California & Hawaii region of the Pacific Geographic Area of the U.S. which includes California and Hawaii.

Region 6, Pacific Northwest Region: The Pacific Northwest Region is within the norther region of the Pacific Geographic Area which includes Oregon and Washington.

Region 8, Southern Region: The Southern Region is within the Southern Geographic Area of the U.S. which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Oklahoma, and Virginia.

Region 9(a), Eastern – Northern Region: The Eastern Region is within the Eastern Geographic Area of the U.S. which includes Connecticut, Delaware, Main, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and West Virginia.

Region 9(b), Eastern – Central Region: The Northern Central Region is within the Northern Central Geographic Area of the U.S. which includes Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin.

Region 10(a), Alaska – Northern Region: The Alaska – Northern Region is within the norther and western areas of Alaska that is part of the Pacific Geographic Area of the U.S. The Alaska – Northern Region includes the following boroughs (counties): Nome, North Slope, and the Northwest Arctic.

Region 10(b), Alaska – Coastal Region: The Alaska – Coastal Region is within the coastal areas of Alaska that is part of the Pacific Geographic Area. The Alaska – Coastal Region includes the following boroughs (counties): Aleutians East, Aleutians West, Anchorage, Bethel, Bristol Bay, Denali, Dillingham, Haines, Juneau, Kenai Peninsula, Ketchikan Gateway, Kodiak Island, Lake and Peninsula, Matanuska Susitna, Prince Wales Ketchikan, Sitka, Skagway Hoonah Angoon, Valdez Cordova, Wade Hampton, Wrangell Petersburg, and Yakutat.

Region 10(c), Alaska – Interior Region: The Alaska – Interior Region is within the norther and western areas of Alaska that is part of the Pacific Geographic Area. The Alaska – Interior Region includes the following boroughs (counties): Yukon Koyukuk, Fairbanks North Star, and Southeast Fairbanks.

Table 11-1. U.S. Forest Service Forest Regions

Forest Region:	Geographical Area:	States Within	Fuel Loading (ton/acre)
1	Rocky Mountain	Montana, northern Idaho, North Dakota, northwestern South Dakota, northeastern Washington, and northwestern Wyoming	60
2	Rocky Mountain	Colorado, Nebraska, Kansas, most of Wyoming and most of South Dakota	30
3	Rocky Mountain	Arizona and New Mexico	10
4	Rocky Mountain	Southern Idaho, Nevada, Utah, and western Wyoming	8
5	Pacific Southwest	California and Hawaii	18
6	Pacific Northwest	Oregon and Washington	60
8	Southern	Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Oklahoma, and Virginia	9
9(a)	Eastern	Connecticut, Delaware, Main, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and W. Virginia	11
9(b)	Northern Central	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin	11
10(a)	Pacific Northwest	Alaska northern counties	16
10(b)	Pacific Northwest	Alaska coastline counties	60
10(c)	Pacific Northwest	Alaska interior counties	11

SOURCE: Section 13.1 – "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

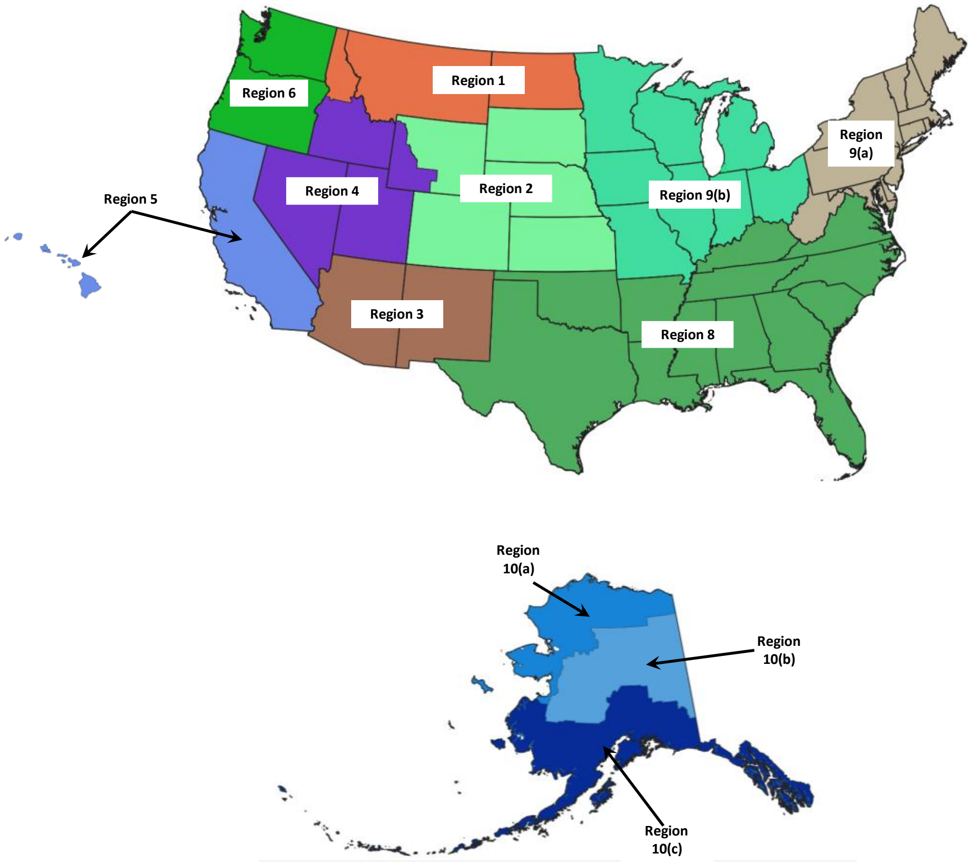


Figure 11-2. Map of U.S. Forest Service Forest Regions

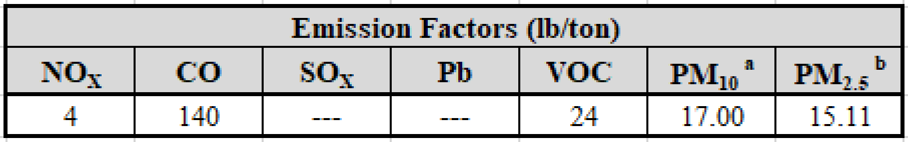
11.2 Wildfires

Wildfires are uncontrolled fires that burn in the wildland vegetation (forests, grasslands, savannas, and other ecosystems), often in rural areas. The size, intensity, and occurrence of wildfires depends directly on the meteorological conditions, the species of vegetation, moisture content of the vegetation, and the weight of consumable fuel per acre (available fuel loading). Once a fire begins, the dry combustible material is consumed first. If the energy release is large and of sufficient duration, the drying of green, live material occurs, with subsequent burning of this material as well. Under proper environmental and fuel conditions, this process may initiate a chain reaction that results in a widespread conflagration.

11.2.1 Wildfire Emission Factors

Estimating emissions from wildfires is difficult because the amount of pollution emitted into the atmosphere is likely based on the intensity and direction of the wildfire, which are influenced by several variables. These variables include, but are not limited to, wind velocity, ambient temperature, relative humidity, and topography. However, the most important factor in wildfire intensity is likely the fuel itself – specifically the vegetation species and moisture content. The regions developed by the USFS have their own set of criteria pollutant EFs. These EFs were developed for each U.S. Forest Service Region based on the expected vegetation and fuel loading factor. These EFs are provided in Table 11-2 and Table 11-3.

Table 11-2. Criteria Pollutant Emission Factors for Wildfires



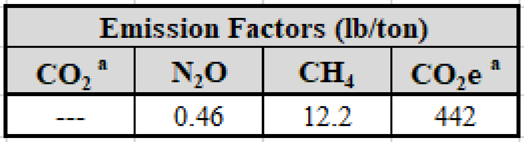
Emission Factors (lb/ton)						
NO_X	CO	SO_X	Pb	VOC	PM_{10} [a]	$PM_{2.5}$ [b]
4	140	---	---	24	17.00	15.11

SOURCE: Section 13.1 – "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

a. Source document provides emission factor for total PM; total PM conservatively assumed to be equal to PM10.

b. Source document provides emission factors for PM. These values calculated using the PM_{10} and $PM_{2.5}$ fraction from Krause, Mike and Steve Smith, "Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance Thresholds," South Coast Air Quality Management District, October 2006.

Table 11-3. Greenhouse Gas Emission Factors for Wildfires



Emission Factors (lb/ton)			
CO_2 [a]	N_2O	CH_4	CO_2e [a]
---	0.46	12.2	442

SOURCE: Section 13.1 – "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

a. CO2e calculated by summing the product of the emission factors for N2O, and CH4 and their respective Global Warming Potentials (GWP). Emissions of CO2 from this source as well as other biogenic sources are part of the carbon cycle, and as such are typically not included in greenhouse gas emission inventories.

11.2.2 Wildfire Emission Calculation

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. Wildfire emissions are estimated from the fuel loading (L), the area burned, and pollutant-specific EFs:

$$E_{Pol} = \frac{L \times EF_{Pol} \times A}{2,000}$$

Equation 11-1

Where:

E_{Pol} = Total Emissions of Specified Pollutant (ton)
L = Fuel Loading Consumed (ton/acre, mass of forest fuel/unit land area), See Table 11-1for default values.

EF_{Pol} = Emission Factor for Specified Pollutant (lb/ton)
See Table 11-2 and Table 11-3.
A = Area of Land Burned (acre)
2,000 = Conversion Factor from lb to ton (lb/ton)

A detailed control volume describing the calculation of emissions from wildfires is depicted in Figure 11-3

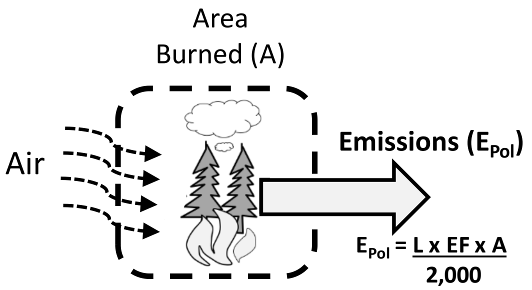


Figure 11-3. Wildfire Control Volume

11.2.3 Wildfire Example Problem

Last year, a wildfire consumed 6.5 acres of land at Eglin AFB. Calculate the CO, VOC, PM10, and CO_2e emissions from this wildfire.

<u>Step 1</u> – Determine the fuel loading factor. Since the occurred at Eglin AFB, which is in Florida, the fire was within the Southern Forest Region. The first step involves determining the fuel loading factor which, according to Table 11-2 for the Southern Forest Region the default fuel loading factor is 9 ton/acre.

<u>Step 2</u> – Determine the emission factors. According to Table 11-2 the EFs for CO, VOC, PM_{10}, and CO_2e are **140, 24, 17, and 442.08 lb/ton,** respectively.

<u>Step 3</u> – Calculate emissions. Using the area burned (A), the fuel loading factor (L), the EFs recorded in Step 2, and the pound to ton conversion factor. The emissions of each pollutant are calculated as follows:

$$\boldsymbol{E_{Pol} = \frac{L \times EF_{Pol} \times A}{2,000}}$$

$$E_{CO} = \frac{9\frac{\cancel{ton}}{\cancel{acre}} \times 140\frac{\cancel{lb}}{\cancel{ton}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E(CO) = 4.1\ ton}}$$

$$E_{VOC} = \frac{9\frac{\cancel{ton}}{\cancel{acre}} \times 24\frac{\cancel{lb}}{\cancel{ton}} \times 6.5\ \cancel{acre}}{2{,}000\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E(VOC) = 0.7\ ton}}$$

$$E_{PM10} = \frac{9\frac{\cancel{ton}}{\cancel{acre}} \times 17\frac{\cancel{lb}}{\cancel{ton}} \times 6.5\ \cancel{acre}}{2{,}000\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E(PM10) = 0.5\ ton}}$$

$$E_{CO_2e} = \frac{9\frac{\cancel{ton}}{\cancel{acre}} \times 442.08\frac{\cancel{lb}}{\cancel{ton}} \times 6.5\ \cancel{acre}}{2{,}000\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E(CO_2e) = 12.9\ ton}}$$

11.3 Prescribed Burning

Prescribed burning is a cost-effective method for the management of forests, ranges, and wetlands to accomplish natural resource management objectives. These objectives may include the treatment of an area to reduce the potential for wildfires, removing logging residues, controlling insects and disease, increasing water yield, or controlling insect population and plant overgrowth without the use of herbicides and pesticides. Prescribed burning is carried out by adhering to a strict plan that stipulates the required weather conditions and burning procedures, including an acceptable temperature range, moisture level, fuel used for ignition, and ignition method.

The combustion process associated with prescribed burning is composed of four phases: preheating, flaming, glowing, and smoldering. Each phase produces different amounts of emissions relative to each other due to the variances in combustion temperatures and combustion efficiencies. Therefore, the total emissions from prescribed burning depend on the time spent in each phase. The preheating phase is typically the "cleanest" phase since few pollutants are emitted into the atmosphere. In contrast, the smoldering phase describes the portion of the process in which combustion is incomplete and inefficient, resulting in a much higher ratio of emitted pollutants per fuel consumed. The combustion efficiency varies in the flaming and glowing phases which, in turn, leads to varying amounts of emitted pollutants.

11.3.1 Prescribed Burning Fuel Load Composition

While Table 11-1provides the default Fuel Loading (weight of consumable fuel per acre) for each U.S. Forest Service Region, it does not differentiate the various forest species and their prevalence. Given each species burns differently, a more accurate estimate of emissions can be accomplished through further defining the relative makeup of the Fuel Loading by species. Default regional fuel load compositions in Table 11-1, are generally used for general planning purposes and rough estimates.

Table 11-4. Default Fuel Load Composition by Geographic Area

Forest Region:	1	2	3	4	5	6
Geographical Area:	Rocky Mountain	Rocky Mountain	Rocky Mountain	Rocky Mountain	Pacific Southwest	Pacific Northwest
Forest Species						
Slash	50%	50%	50%	50%	0%	42%
Conifer - Long Needle	0%	0%	0%	0%	0%	6%
Conifer - Short Needle	20%	20%	20%	20%	15%	29%
Conifer - Mixed	0%	0%	0%	0%	0%	19%
Grassland	20%	20%	20%	20%	10%	0%
Sagebrush	0%	0%	0%	0%	35%	0%
Chaparral	0%	0%	0%	0%	20%	0%
Pinyon/Juniper	0%	0%	0%	0%	20%	0%
Hardwood	0%	0%	0%	0%	0%	4%
Palmetto/Gallberry	0%	0%	0%	0%	0%	0%
Other	10%	10%	10%	10%	0%	0%

Forest Region:	8	9(a)	9(b)	10(a)	10(b)	10(c)
Geographical Area:	Southern	Eastern	Northern Central	Pacific Northwest	Pacific Northwest	Pacific Northwest
Forest Species						
Slash	20%	50%	50%	42%	42%	42%
Conifer - Long Needle	0%	0%	0%	6%	6%	6%
Conifer - Short Needle	30%	10%	10%	29%	29%	29%
Conifer - Mixed	0%	0%	0%	19%	19%	19%
Grassland	10%	30%	30%	0%	0%	0%
Sagebrush	0%	0%	0%	0%	0%	0%
Chaparral	0%	0%	0%	0%	0%	0%
Pinyon/Juniper	0%	0%	0%	0%	0%	0%
Hardwood	0%	0%	0%	4%	4%	4%
Palmetto/Gallberry	35%	0%	0%	0%	0%	0%
Other	5%	10%	10%	0%	0%	0%

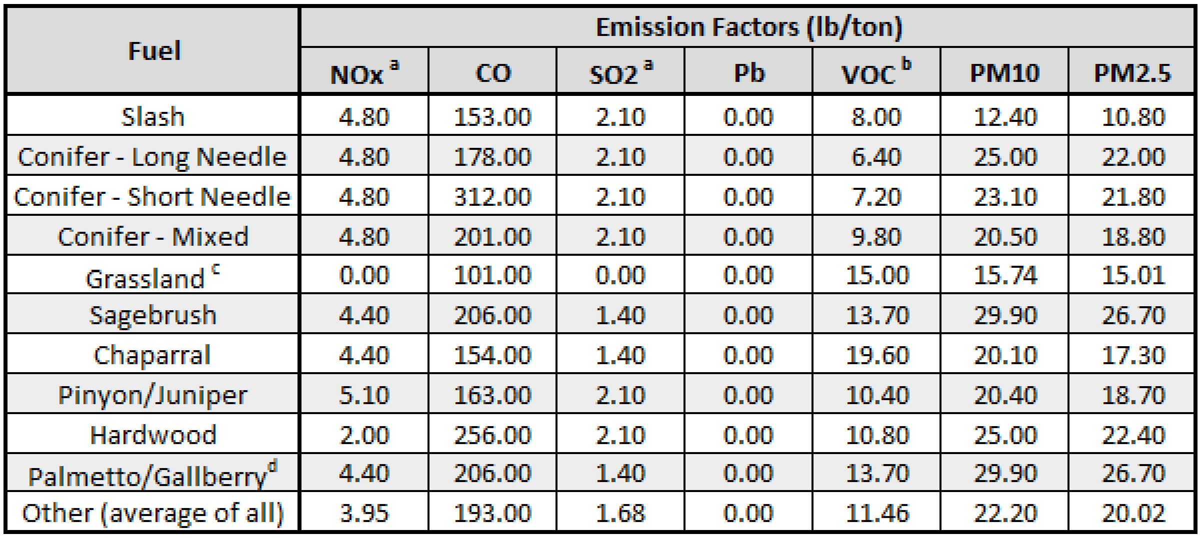
SOURCE: Section 13.1, Table 13.1-4 – "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

The defaults are regional averages based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided. Generally, these default values should not be used to develop emission inventories and control strategies.

11.3.2 Prescribed Burning Emission Factors

AP-42 provides several EFs for prescribed burning in Section 11.1. Details regarding each source are provided in the following sections.

Table 11-5. Criteria Pollutant Emission Factors for Prescribed Burns



Fuel	Emission Factors (lb/ton)						
	NOx [a]	CO	SO2 [a]	Pb	VOC [b]	PM10	PM2.5
Slash	4.80	153.00	2.10	0.00	8.00	12.40	10.80
Conifer - Long Needle	4.80	178.00	2.10	0.00	6.40	25.00	22.00
Conifer - Short Needle	4.80	312.00	2.10	0.00	7.20	23.10	21.80
Conifer - Mixed	4.80	201.00	2.10	0.00	9.80	20.50	18.80
Grassland [c]	0.00	101.00	0.00	0.00	15.00	15.74	15.01
Sagebrush	4.40	206.00	1.40	0.00	13.70	29.90	26.70
Chaparral	4.40	154.00	1.40	0.00	19.60	20.10	17.30
Pinyon/Juniper	5.10	163.00	2.10	0.00	10.40	20.40	18.70
Hardwood	2.00	256.00	2.10	0.00	10.80	25.00	22.40
Palmetto/Gallberry [d]	4.40	206.00	1.40	0.00	13.70	29.90	26.70
Other (average of all)	3.95	193.00	1.68	0.00	11.46	22.20	20.02

SOURCE (unless otherwise stated): “NWGC Smoke Management Guide for Prescribed Fire,” National Wildfire Coordinating Group (NWCG), Fire Use Working Team, November 2020.

a. SOURCE: Johnson, T.J.; Yokelson, R.J.; Akagi, S.K.; Burling, I.R.; Weise, D.R.; Urbanski, S.P.; Stockwell, C.E.; Reardon, J.; Lincoln, E.N.; Profeta, L.T.M.; Mendoza, A.; Schneider, M.D.W.; Sams, R.L.; Williams, S.D.; Wold, C.E.; Griffith, D.W.T.; Cameron, M.; Gilman, J.B.; Warneke, C.; Roberts, J.M.; Veres, P.; Kuster, W.; de Gouw, J. 2013. Final Report for SERDP Project RC-1649: Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns. Technical Report PNNL-23025. Richland, WA: U.S. Department of Energy, Pacific Northwest National Laboratory. 269p.

b. Emission factor given for VOC is the same as that provided in the source document for non-methane hydrocarbons.

c. Section 2.5 – “Open Burning, “Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

d. Emission factors for sagebrush used.

Pb assumed 0.00, no data available.

Table 11-6. Greenhouse Gas Emission for Prescribed Burns

Fuel	Emission Factors (lb/ton)			
	CO_2	N_2O [a]	CH_4	CO_2e [b]
Slash	3,349	0.46	9.40	3,721
Conifer - Long Needle	3,202	0.46	8.20	3,544
Conifer - Short Needle	3,082	0.46	11.00	3,494
Conifer - Mixed	3,165	0.46	12.80	3,622
Grassland [c]	2,149	0.08	4.50	2,285
Sagebrush	3,126	0.46	11.90	3,561
Chparral	3,257	0.46	5.70	3,537
Pinyon/Juniper	3,231	0.46	12.00	3,668
Hardwood	3,072	0.46	13.20	3,539
Palmetto/Gallberry [d]	3,126	0.46	11.90	3,561
Other (average of all)	3,076	0.42	10.06	3,453

SOURCE (unless otherwise stated): "NWGC Smoke Management Guide for Prescribed Fire," National Wildfire Coordinating Group (NWCG), Fire Use Working Team, November 2020.

a. SOURCE: Section 13.1 – "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

b. CO2e calculated by summing the product of the emission factors for CO2, N2O, and CH4 and their respective Global Warming Potentials (GWP). The emission factors were taken from 40 CFR 98 Tables C-1 andC-2 and the GWP for CO2, N2O, and CH4 are 1, 298, and 25, respectively.

c. Section 2.5 – "Open Burning, "Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

d. Emission factors for sagebrush used.

11.3.3 Prescribed Burning Calculation

The importance of both fuel type and fuel loading on the fire process cannot be overemphasized. Prescribed Burning emissions are estimated from the fuel loading (L), the area burned, and pollutant-specific EFs:

$$\boldsymbol{E_{Pol} = \sum\left(\frac{EF_{Pol} \times S_i \times A}{2,000}\right) = \sum\left(\frac{EF_{Pol} \times L \times (M_i \div 100\%) \times A}{2,000}\right)}$$

Equation 11-2

Where:

E_{Pol} = Total Emissions of Specified Pollutant (ton)
EF_{Pol} = Emission Factor for Specified Pollutant (lb/ton)
See Table 11-2 and Table 11-3 for EF values.
i = Specified Forest Species
M_i = Species Mix or Composition (% of total fuel)

S_i = Species-specific Fuel Loading (ton/acre) = L x (Mi÷100%)
L = Fuel Loading Consumed (ton/acre, mass of forest fuel/unit land area), See Table 11-1for default values.
A = Area of Land Burned (acre)
2,000 = Conversion Factor from lb to ton (lb/ton)

A detailed control volume describing the calculation of emissions from wildfires is in Figure 11-4

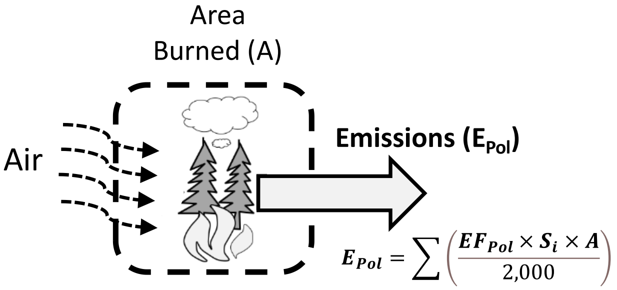


Figure 11-4. Prescribed Burning Control Volume

11.3.4 Prescribed Burning Example Problem

Eglin AFB intends to perform a 50-acre prescribed burn. Calculate the NOx, VOC, and $PM_{2.5}$ emissions from this wildfire.

<u>Step 1</u> – Determine the fuel loading factor (L). Since the prescribed burn will occur at Eglin AFB, which is in Florida, the fire will be within the Southern Forest Region. The first step involves determining the fuel loading factor which, according to Table 11-1for the Southern Forest Region the default fuel loading factor is 9 ton/acre.

<u>Step 2</u> – Determine the species mix or composition. Again, since the prescribed burn will occur at Eglin AFB, which is in Florida, the fire will be within the Southern Forest geographic area. The next step involves determining the species-specific fuel loading mix, according to Table 11-4:

Slash = 20%

Conifer - Short Needle = 30%

Grassland = 10%

Palmetto/Gallberry = 35%

Other = 5%

Step 3 – **Determine the species-specific fuel loading.** Species-specific fuel loading (S_i) is the relative makeup of the Fuel Loading by species and is calculated as S_i = L x (Mi÷100%).

S_i(Slash) = 9 ton/acre x (20%÷100%) = 1.8 ton/acre

S_i(Conifer - Short Needle) = 9 ton/acre x (30%÷100%) = 2.7 ton/acre

S_i(Grassland) = 9 ton/acre x (10%÷100%) = 0.9 ton/acre

S_i(Palmetto/Gallberry) = 9 ton/acre x (35%÷100%) = 3.15 ton/acre

S_i(Other) = 9 ton/acre x (5%÷100%) = 0.45 ton/acre

Step 3 – **Determine the emission factors.** According to Table 11-5 and Table 11-6, the EFs for NOx, VOC, and $PM_{2.5}$ are:

Fuel	Emission Factors (lb/ton)		
	NOx	VOC	PM2.5
Slash	4.80	8.00	10.80
Conifer - Short Needle	4.80	7.20	21.80
Grassland	0.00	15.00	15.01
Palmetto/Gallberry	4.40	13.70	26.70
other (average of all)	3.50	10.98	18.58

Step 4 – **Calculate emissions.** Using the area burned (A), the species-specific load (S_i), the EFs recorded in Step 3, and the pound to ton conversion factor, the emissions of each pollutant are calculated as follows:

$$\boldsymbol{E_{Pol} = \sum\left(\frac{EF_{Pol} \times S_i \times A}{2,000}\right)}$$

$$E_{NOx} = \frac{4.8\frac{\cancel{lb}}{\cancel{ton}} \times 1.8\frac{\cancel{ton}}{\cancel{acre}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton} + \frac{4.8\frac{\cancel{lb}}{\cancel{ton}} \times 2.7\frac{\cancel{ton}}{\cancel{acre}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton} + \frac{0.0\frac{\cancel{lb}}{\cancel{ton}} \times 0.9\frac{\cancel{ton}}{\cancel{acre}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton} + \frac{4.4\frac{\cancel{lb}}{\cancel{ton}} \times 3.15\frac{\cancel{ton}}{\cancel{acre}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton} + \frac{3.5\frac{\cancel{lb}}{\cancel{ton}} \times 0.45\frac{\cancel{ton}}{\cancel{acre}} \times 6.5\ \cancel{acre}}{2,000\ \cancel{lb}/ton}$$

$$\boxed{E_{NOx} = 0.11\ ton}$$

$$\boldsymbol{E_{VOC}} = \frac{\mathbf{8.0}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{1.8}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{7.2}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{2.7}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{15.0}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{0.9}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton}$$

$$+ \frac{\mathbf{13.7}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{3.15}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{10.98}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{0.45}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E_{VOC} = 0.29\ ton}}$$

$$\boldsymbol{E_{PM2.5}} = \frac{\mathbf{10.8}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{1.8}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{21.8}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{2.7}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{15.01}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{0.9}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton}$$

$$+ \frac{\mathbf{26.7}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{3.15}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton} + \frac{\mathbf{18.58}\frac{\cancel{lb}}{\cancel{ton}} \times \mathbf{0.45}\frac{\cancel{ton}}{\cancel{acre}} \times \mathbf{6.5}\ \cancel{acre}}{\mathbf{2{,}000}\ \cancel{lb}/ton}$$

$$\boxed{\boldsymbol{E_{PM2.5} = 0.57\ ton}}$$

11.4 References

40 CFR 60 Subpart Cb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Cb-Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that are Constructed on or Before September 20, 1995," U.S. Environmental Protection Agency

40 CFR 60 Subpart Eb, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart Eb-Standards of Performance for Municipal Waste Combustors for which Construction is Commenced After June 19, 1996," U.S. Environmental Protection Agency

40 CFR 60 Subpart AAAA, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart AAAA-Standards of Performance for Small Municipal Waste Combustion Units for which Construction is Commenced After August 30,1999," U.S. Environmental Protection Agency

40 CFR 60 Subpart BBBB, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart BBBB-Emissions Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999," U.S. Environmental Protection Agency

40 CFR 60 Subpart CCCC, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart CCCC-Standards of Performance for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart DDDD, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart DDDD-Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units," U.S. Environmental Protection Agency

40 CFR 60 Subpart EEEE, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart EEEE-Standards of Performance for Other Solid Waste Incineration Units for which Construction is Commenced After December 9, 2004, or for

which Modification or Reconstruction is Commenced on or After June 16, 2006," U.S. Environmental Protection Agency

40 CFR 60 Subpart FFFF, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New Stationary Sources, Subpart FFFF-Emissions Guidelines and Compliance Times for Other Solid Waste Incineration Units that Commenced Construction on or Before December 9, 2004," U.S. Environmental Protection Agency

40 CFR 60 Subpart C, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion Sources," U.S. Environmental Protection Agency

40 CFR 98, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C

Brown 1974, "Handbook for Inventorying Downed Woody Material;" James K. Brown, USDA
Forest Service general Technical Report INT-16, Intermountain Forest & Range Experiment Station, Ogden, Utah; 1974

Hardy 9996, "Guidelines for Estimating Volume, Biomass, and Smoke Production for Piled Slash"; Colin C. Hardy, USDA Forest Service General Technical Report PNW-GTR-364. Pacific Northwest Research Station, Portland, Oregon; 1996

USEPA 1995, Section 2.5-"Open Burning," Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1996

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12 MITIGATION

12.1 Introduction

Mitigation is an important mechanism for agencies to use to avoid, minimize, rectify, reduce, or compensate the adverse environmental impacts associated with their actions. Federal Agencies typically rely upon mitigation to reduce environmental impacts through modification of proposed actions. Agencies also depend on the development of mitigation alternatives during the NEPA and General Conformity process. Under NEPA, if a proposed action is not categorically excluded, the Federal agency must determine if the action will have a significant impact on the environment. The agency must prepare a Finding of No Significant Impact (FONSI) if it is determined that the action will not have a significant impact on the environment. The FONSI must present evidence to support this conclusion and state all mitigation that will be taken, if any. If, however, the agency determines that the action may have a significant impact on the environment, the agency must prepare an EIS. All mitigation measures not included in the proposed action or alternatives must be defined within an EIS. After public review, the ROD serves as the final decision of the responsible agency and describes any monitoring and enforcement programs for mitigation that the agency is committed.

Similarly, under General Conformity (GC), mitigation measures may be required to ensure that the Federal action conforms to the applicable implementation plan. All mitigation measures must be identified and an implementation schedule containing explicit timelines must be described. Mitigation measures may be modified as necessary due to changes in circumstances if the new measures continue to conform to the applicable implementation plan (40 CFR 93.160). If the emissions cannot be mitigated sufficiently to conform with the implementation plan, the action cannot proceed.

Mitigation measures minimize adverse environmental effects of a federal action with the intention of reducing the environmental impacts below a threshold of significance. Ideally, the mitigation effort would reduce emissions associated with a proposed action below de minimis thresholds. To demonstrate the reduction results in emissions below de minimis thresholds, the total direct and indirect emissions from the proposed action must be fully offset with the affected nonattainment or maintenance area so that there is no net increase in emissions of the pollutants of interest above the de minimis thresholds. Typically, the emissions reductions from mitigation measures to demonstrate conformity must occur within the same calendar year as the emissions subject to conformity. However, some states do allow exceptions to this rule on a case-by-case basis. The allowances can neither cause nor exacerbate the violation of the NAAQS nor impede an area’s attainment strategy.

Some regulating agencies may approve mitigation measures of different precursors of the same pollutant. For example, in the case of O_3 whose precursors are VOCs and NO_X, an action which reduces VOCs may be approved to offset the action's increase in NO_X emissions. For approval of these mitigation measures, these trades must be allowable under local regulations and have a demonstrated environmental benefit.

Some states have also established mandates regarding mitigation. For example, in 1970, California enacted the California Environmental Quality Act (CEQA) which requires public agencies to prepare an Environmental Impact Report (EIR) for projects which may adversely affect the environment. The EIR must identify the adverse effects, propose alternatives, and describe how those effects can be mitigated. Under CEQA, public agencies are required to implement feasible mitigation measures, or establish and implement alternatives that would mitigate significant adverse effects to the environment.

The acceptable methodologies, algorithms, and emission factors for quantifying mitigated and unmitigated air emissions are described in the latest versions of the AF Mobile, Stationary, and Transitory Guides. Additionally, the Air Force Air Quality Environmental Impact Analysis Process (EIAP) Guide serves as the DAF's implementing tool for NEPA and provides the DAF with a framework on how to comply with NEPA and the President's CEQ. The following pages detail several feasible measures that can be reasonably expected to reduce air emissions from several pollutant emitting sources.

12.2 Fugitive Dust (PM_{10})

Dust is defined as suspended geologic, organic, synthetic, or dissolved solids and does not include the particulate matter emitted by internal or external combustion processes. Fugitive dust includes the particulate matter which cannot reasonably pass through a chimney, stack, or vent. Emissions of fugitive dust are generated by the forces of wind or machinery acting on exposed material. Fugitive dust primarily consists of soil, though it may also be emitted from powdered or aggregate materials deposited on the ground or from vehicle trackout. Additionally, dust emissions from paved roads include tire and break wear particles. Activities/sources which may generate fugitive dust include Construction and Demolition, Materials Handling, Paved Roads, Unpaved Roads, and Storge Piles (SCAQMD 2010).

12.2.1 Construction and Demolition

Fugitive dust emissions generated during construction are associated with land clearing, excavation, drilling, blasting, and cut and fill operations as well as from vehicle traffic at the construction site. While daily fugitive dust emissions may vary substantially, the total emitted volume of fugitive dust is "proportional to the area of land being worked and level of construction activity" (WRAP 2006). There are several dust control methods which may or may not be feasible for every construction project. Dust suppressant methods include:

- **Watering** – Typically readily available and relatively inexpensive, using water as a dust suppressant does not have any negative environmental impact, though it is effective only for a short period of time which varies depending on site temperature and humidity.
- **Chemical Stabilizers** – include a variety of substances such as:
  - <u>Water absorbing products</u> (e.g., calcium chloride brine, magnesium chloride brine, sodium chloride) – suitable for low humidity climates but must be frequently reapplied in dry climates, are corrosive, and negatively impact water quality and aquatic life.
  - <u>Organic petroleum products</u> (e.g., asphalt emulsions, dust oils, petroleum resins) – not suitable for non-traffic areas and contain polycyclic aromatic hydrocarbons which are considered HAPs and may result in significant negative environmental impacts.
  - <u>Organic non-petroleum products</u> (e.g., ligninsulfonates, vegetable oils, oil emulsions) – effectiveness is negatively impacted (and potentially completely impaired) by rain while also potentially detrimental to freshwater aquatic life.
  - <u>Polymer products</u> (e.g., polyvinyl acetates, vinyl acrylics) – non-toxic and non-corrosive, these products increase the load bearing strength of all soil types and serve to prevent wind and water erosion.
  - <u>Synthetic Products</u> (e.g., iso-alkane compounds) – easy to apply and, since these products utilize environmentally friendly synthetic fluids, they are considered non-hazardous under OSHA, EPA, and US DOT.
- **Sand Fences** – can be used for beautification and erosion control in some areas, this method is most effective when used in conjunction with chemical stabilizers.
- **Perimeter Sprinklers** – generally readily available without negative environmental impact, these work best when used in conjunction with other measures.
- **Tire Cleaning Systems at Site Exit** – this method serves to reduce or prevent trackout from construction vehicles as they travel from the work site onto paved roads.
- **On-Site Speed Control** – commonly used method which reduces the generated fugitive dust by reducing soil disturbance caused by on-site vehicles.

Calculation of unmitigated emissions under this subcategory utilize site data and those algorithms found in the construction chapter of this guide as well as the on-road vehicle chapter of the mobile guide. Specifically, for active demolition and debris removal, refer to section 4.3.1.1 of this guide and section 4.3.1.2 for all other construction activities. For guidance on emissions estimates for trackout and traffic on unpaved roads, refer to section 5.2.2 of the Mobile Guide. If the particulate control efficiency of a mitigation measure is known or may be estimated, it may be applied to the uncontrolled emissions to determine the extent of the mitigated dust emissions. Examples of mitigation measures to control fugitive dust resulting from construction and demolition (with their respective control efficiency) is provided in Table 12-1.

Table 12-1. Mitigation Measures for Controlling Fugitive Dust from Construction and Demolition

Source Activity	Mitigation Measure	PM_{10} Control Efficiency	Comments
Active demolition and debris removal	Apply water every 4 hours to the area within 100 feet of a structure being demolished	36%	
Trackout	Use a gravel apron, 25 feet long by road width	46%	
Trackout [a]	Install wheel washers at the entrance to construction sites for all exiting trucks	50%	SCAQMD, SIP for PM_{10} in the Coachella Valley, 1990. pgs. 4-11
Post-demolition stabilization	Apply dust suppressants (e.g., polymer emulsion) to disturbed areas upon completion of demolition	84%	For actively disturbed areas
Demolition Activities	Apply water to disturbed soils after demolition is completed or at the end of each day of cleanup	10%	14-hour watering schedule
Demolition Activities	Prohibit demolition activities when wind speeds exceed 25 mph	98%	Estimated for high wind days in absence of soil disturbance activities.
Construction Activities	Apply water at various intervals to disturbed areas within construction site	61%	3.2-hour watering interval
Scraper loading and unloading	Require minimum soil moisture of 12% for earthmoving	69%	AP-42 emission factor equation for materials handling due to increasing soil moisture from 1.4% to 12%
Construction traffic	Limit on-site vehicle speeds to 15 mph	57%	Assume linear relationship between PM_{10} emissions and uncontrolled vehicle speed of 35 mph
Wind erosion from inactive areas [a]	Apply chemical soil stabilizers on inactive construction areas (disturbed lands within construction projects that are unused for at least four consecutive days)	Up to 80%	Section 13.2.2 - "Unpaved Roads," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006.
Wind erosion from inactive areas [a]	Plant tree windbreaks on the windward perimeter of construction projects if adjacent to open land.	4% (15% for mature trees)	SCAQMD, SIP for PM_{10} in the Coachella Valley, 1990. pgs. 5-15
Wind erosion from inactive areas [a]	Plant vegetative ground cover in disturbed areas as soon as possible	5% - 99% (based on planting plan)	SCAQMD, SIP for PM_{10} in the Coachella Valley, 1990. pgs. 5-15

Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation measures that address the same source of emissions would not be the sum of both measures).

Source (unless otherwise stated): Countess Environmental, WRAP Fugitive Dust Handbook, September 7, 2006. Table provides cited source's original references.

a. Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008.

12.2.2 Materials Handling

Fugitive dust emissions from materials handling refer to those suspended particulates generated during the handling and transfer of materials between processes. These emissions may be generated during loading and loadout of material at a storage pile, at transfer points between conveyors or vehicles used to haul aggregate, or through disturbances of the material in storage piles caused by strong winds. Total fugitive dust emissions from this subcategory are dependent upon the characteristics of the storage pile such as its age, moisture content, and proportion of aggregate fines. Generally, the older the storage pile, the lower its potential to generate fugitive dust. This is partially due to an increased moisture content of the interior of the storage pile, either from rain or watering, which slows the drying of the aggregate.

Worst-case conditions for dust generated through material handling occur under dry, windy conditions. Therefore, the principal means for the control of these emissions is with watering and chemical wetting agents, though other measures exist. The most common control measures for materials handling and their respective control efficiencies are provided in Table 12-2.

Table 12-2. Materials Handling Mitigation Measure Control Efficiencies

Mitigation Measure	PM_{10} Control Efficiency	Comments
Continuous water spray at conveyor transfer point	62%	The control efficiency achieved by increasing the moisture content of the material from 1% to 2% is calculated utilizing the AP-42 emission factor equation for materials handling which contains a correction term for moisture content.
Haul trucks shall maintain at least 2'0" of freeboard	90%	Monterey Bay Unified Air Pollution Control District (MBUAPCD)
Cover all trucks hauling dirt, sand, or loose materials	90%	Monterey Bay Unified Air Pollution Control District (MBUAPCD)

Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation measures that address the same source of emissions would not be the sum of both measures).

Source: Countess Environmental, WRAP Fugitive Dust Handbook, September 7, 2006. Table provides cited source's original references.

If the mean wind speed and moisture content of the material is known or can be estimated, the PM_{10} emissions may be calculated using Equation 12-1.

$$E(Pol) = k \times 0.0032 \times \frac{\left(U/5\right)^{1.3}}{\left(M/2\right)^{1.4}} \times (1 - CE) \times A$$

Equation 12-1

Where,

E(Pol) = Annual PM_{10} or $PM_{2.5}$ emissions (lb/yr)
K = Particle size multiplier. **This is 0.35 for PM_{10} and 0.053 for $PM_{2.5}$.**
U = Mean wind speed (mph)
M = Material moisture content (%)
CE = Control Efficiency. **0 if unmitigated or taken from** Table 12-1**.**
A = Annual throughput (ton/yr)

12.2.3 Paved Roads

Particulate emissions from paved surfaces consist of the loose material on the road surface that is disturbed and resuspended due to the turbulent wake caused from on-road vehicles. The volume of emitted particulate is dependent on the loose material present on the road surface, or surface loading. Over time, the surface loading should reach an equilibrium in which the amount of material resuspended is equal to the amount of material deposited on the road surface. However, this equilibrium can be disrupted for a variety of reasons which may include: trackout, deposition from erosion, and the application of granular materials used for snow and ice control. The equilibrium surface loading values depend upon variables such as vehicle mean speed, average daily traffic, number of lanes, and the fraction of heavy gross weight vehicles. Typical silt loading values for paved roads at select industrial facilities are provided in Table 12-3.

Table 12-3. Typical Silt-Loading Values for Paved Roads at Industrial Facilities

Industry	Silt Loading (g/m^2)	
	Range	Mean
Asphalt Batching	76 - 193	120
Concrete Batching	11 - 12	12
Sand and gravel processing	53 - 95	70

SOURCE: Section 13.2.1 - “Paved Roads,” *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources*, Fifth Edition, U.S. Environmental Protection Agency, January 2011.

Since the volume of emitted dust is a function of the road surface silt loading, the primary control techniques to mitigate these emissions involve removal of the material or prevention of material deposit. Some examples of material removal include vacuum sweeping, water flushing, and broom sweeping or flushing. Preventative examples include paving over unpaved lots or work sites or covering truck loads and are generally more cost effective in the long term than material removal. A summary of control measures and their respective efficiencies is provided in Table 12-4.

Table 12-4. Paved Roads Mitigation Measure Control Volume

Mitigation Measure	Source Component	PM_{10} Control Efficiency	Comments
Implement street sweeping program with non-efficient vacuum units (14-day frequency)	Local streets	7%	MRI, September 1992. For non-PM_{10} efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	11%	
Implement street sweeping program with PM_{10} efficient vacuum units (14-day frequency)	Local streets	16%	MRI, September 1992. For PM_{10} efficient sweepers based on 86% efficient sweeping, 8.6 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
	Arterial/collector streets	26%	
Require streets to be swept by non-efficient vacuum units (once per month frequency)	Local, arterial, and collector streets	4%	MRI, September 1992. For non-PM_{10} efficient sweepers based on 55% efficient sweeping, 5.5 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
Require streets to be swept by PM_{10} efficient vacuum units (once per month frequency)	Local, arterial, and collector streets	9%	MRI, September 1992. For PM_{10} efficient sweepers based on 86% efficient sweeping, 8.6 day equilibrium return time and CA-VMT weighted sweeping frequency (7 to 30 days)
Require wind- or water-borne deposition to be cleaned up within 24 hours after discovery	All Streets	100%	Assumes total cleanup of spill on roadway before traffic resumes
Install pipe-grid trackout-control device	Mud/dirt carryout	80%	Sierra Research, 2003.
Install gravel bed trackout apron (3 in deep, 25ft long and full road width)	Mud/dirt carryout	46	MRI, April 2001
Require paved interior roads to be 100 foot long and full road width, or add 4 foot shoulder for paved roads	Mud/dirt carryout	42	MRI, April 2001

Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original references.

Section 5.2.2 of the latest version of the Mobile Source Guide provides the algorithms needed to calculate fugitive emissions from paved road use. Additionally, the guide includes Air Force-specific emission factors that were calculated using on-road average vehicle weight data. Refer to that section of the Mobile Guide for specific guidance on calculating the uncontrolled emissions from paved road use. Mitigated emissions estimates may then be estimated using this calculated total and the appropriate control method and respective efficiency found in Table 12-4.

12.2.4 Unpaved Roads

As with the travel of vehicles along paved roads, fugitive particulate emissions from unpaved roads are the result of the suspension of particles from the turbulent wake of on-road vehicles. However, the volume of fugitive particulate emissions is generally much higher for travel along unpaved roads with the quantity of dust emissions varying linearly with traffic volume. The force of the wheels on unpaved surfaces pulverizes surface material while continually lifting and dropping particulate while the vehicle is in motion. Emissions from unpaved roads are a function of the surface silt content and increase with increasing average vehicle weight.

Control of emissions from unpaved roads generally fall under one of the following:

- Vehicle restrictions
- Surface improvements, or
- Surface treatments.

Vehicle restrictions reduce dust emissions by lowering the mean vehicle speed or altering the amount and type of vehicle traffic on the road. Lowering the speed limit reduces the turbulence created by each vehicle and reduces the volume of resuspended particulate. Road traffic may be reduced through the implementation of ride sharing or through instituting bussing programs. While dust emissions increase with the increase in the average vehicle weight, the reduction in total vehicle miles traveled on the unpaved roads may result in lower emissions.

Surface improvements work to alter the road surface and are relatively permanent. Paving is the most obvious improvement, though it is not always feasible at a facility or work site and can be cost prohibitive. From an environmental standpoint, it is also important to note that even though a paved surface may improve fugitive dust emissions, a strategy for routine cleaning should be adopted to reduce silt loading, especially if the paved road is near an unpaved road or an unpaved work site with heavy traffic.

Surface treatment are temporary solutions that require periodic application. The reapplication frequency varies with the treatment itself – wet suppression through water application may last less than an hour in extreme summer conditions while chemical dust suppressants may work for several weeks. Since wet suppression works through increasing the material moisture content, the control efficiency of this measure depends on how quickly the road dries. This depends on the amount of water applied; application intervals; number, speed, and average gross weight of the vehicles traveling on the surface, and the meteorological conditions. Chemical dust suppressants change the physical characteristics of the road surface material to form a hardened surface. The control effectiveness of applying chemical dust suppressants depend on the chemical concentration; the amount applied; application intervals; number, speed, and average gross weight of the vehicles traveling on the surface; and meteorological conditions. Table 12-5provides the control efficiencies for control measures on unpaved roads.

Table 12-5. Unpaved Roads Mitigation Measure Control Efficiencies

Mitigation Measure	PM_{10} Control Efficiency	Comments
Limit maximum speed on unpaved roads to 25 mph	44%	Assumes linear relationship between PM10 emissions and vehicle speed and an uncontrolled speed of 45 mph
Pave unpaved roads and unpaved parking areas	99%	Based on comparison of paved road and unpaved road PM10 emission factors
Implement watering twice a day for industrial unpaved road	55%	MRI, April 2001
Apply dust suppressant annual to unpaved parking areas	84%	CARB, April 2002

Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original references.

Section 5.2.2 of the latest version of the Mobile Source Guide provides the algorithms needed to calculate fugitive emissions from unpaved road use. Additionally, the guide includes Air Force-specific emission factors that were calculated using on-road average vehicle weight data. Refer to that section of the Mobile Guide for specific guidance on calculating the uncontrolled emissions from unpaved road use. Mitigated emissions estimates may then be estimated using this calculated total and the appropriate control method and respective efficiency found in Table 12-5.

12.2.5 Storage Piles

Wind erosion may act upon any exposed soils or piles of aggregate material at a facility to generate fugitive dust emissions. The extent of the particulate emission rate depends upon the erosion potential of the surface material. Aggregate materials or those that have hardened surfaces, have a lower erosion potential and experience rapidly decaying particulate emission rates during erosion events. Sand and loose soils, however, sustain high particulate emission rates due to their high erosion potentials.

Control measures used to reduce the erosion potential of storage piles either include stabilizing the surface or through shielding. Surface stabilization is achieved through periodic watering of the material while shielding involves either covering the material or enclosing the pile on at least three sides. Control efficiencies for these measures are provided in Table 12-6.

Table 12-6. Storage Pile Wind Erosion Mitigation Measure Control Efficiencies

Mitigation Measure	PM_{10} Control Efficiency	Comments
Require construction of 3-sided enclosures with 50% porosity	75%	Sierra Research, 2003. Determined through modeling of open area windblown emissions with 50% reduction in wind speed and assuming no emission reduction when winds approach open side
Water the storage pile by hand or apply cover when wind events are declared	90%	Fitz et al., April 2000

Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original references.

Section 13.2.5 of AP-42 describes a procedure for calculating particulate emissions from wind erosion of storage piles. However, a simpler method is presented here. For active storage piles, the EPA established the following algorithm for calculating fugitive particulate through wind erosion:

$$\boldsymbol{E(Pol) = k \times \frac{s}{1.5} \times \frac{365 \times (365 - p)}{235} \times \frac{f}{15} \times (1 - CE) \times A}$$

Equation 12-2

Where,

E(Pol) = Annual emissions of PM_{10} or $PM_{2.5}$ (lb/yr)
k = Particle size multiplier. **This is 0.85 for PM_{10} and 0.13 for $PM_{2.5}$.**
s = Silt content of the material (wt. %)
p = Number of days in a year with at least 0.01 inch of precipitation
f = Percentage of time unobstructed wind speed exceeds 12 mph at the mean pile height
CE = Control efficiency. **0 if unmitigated or use** Table 12-6Table 12-6**.**
A = Total size of surface (acre)

Local climatological data reports from nearby weather stations can provide wind speed and precipitation data needed for calculations.

12.3 Heavy-Duty Equipment

Construction, land clearing, or landfill operation are just a few activities that require the use of heavy-duty off-road equipment. Heavy duty equipment is generally powered by reciprocating internal combustion engines operating on gasoline or diesel fuel. In a reciprocating engine, a piston moves inside a cylinder to compress an air/fuel mixture. The air/fuel mixture combusts and expands, pushing the piston through the cylinder. The piston returns, pushing out the exhaust gases, and the cycle is repeated. Emissions generated through this process include NO_X, CO, VOC, SO_X, PM_{10}, $PM_{2.5}$, as well as GHGs. The EPA has worked to lower emissions from heavy duty equipment by imposing emission limits on manufacturers. However, criteria pollutant emissions from the use of heavy-duty off-road equipment may still be significant and may only be exacerbated if older equipment is used.

Mitigation of emissions from heavy duty equipment use falls into one of three categories:

- Controls on Activity,
- Equipment Engine Repowers, or
- Equipment Retrofitting

Controls on activity limits emissions through limiting the number of vehicles used, the type of fuel used, the hours of operation, and the duration of use. The control efficiencies of many of these measures depend upon the emission rate of the specific piece of equipment used and total operation time. Table 12-7 provides the control efficiencies for this category of mitigation measures.

Table 12-7. Heavy-Duty Activity Limit Mitigation Measure Control Efficiencies

Mitigation Measure	Control Efficiencies					Comments
	CO	NO_X	VOC	SO_X	PM	
Limit Use of Equipment	Refer to Chapter 4 of the latest version of the Mobile Source Guide					
Replace diesel-powered equipment with gasoline-powered	Refer to Chapter 4 of the latest version of the Mobile Source Guide					
Use PuriNO_X emulsified diesel fuel in existing engines	---	14%	---	---	63%	ARB interim verification of 1/31/01

Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation measures that address the same source of emissions would not be the sum of both measures).
Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), *CEQA Air Quality Guidelines*, February 2008
"---" Indicates that no data is available.

Heavy-duty equipment emission rates vary depending on the equipment type and fuel used. To estimate typical emissions and calculate the potential and extent for mitigated emissions, refer to Chapter 4 Non-road engines of the latest version of the Mobile Guide. The extent of mitigated emissions of a proposed measure may be determined using the algorithms and emission factors in that chapter to compare baseline and mitigated emissions. For example, if a mitigation plan calls for the use of gasoline powered equipment in place of diesel-powered equipment to lower NO_X, the total emissions of the proposed gasoline-powered equipment may be calculated and subtracted from the original diesel-powered equipment emissions to estimate the total savings. Equipment engine repower refers to replacing an engine with an updated engine with lower emission rates. The control effectiveness is dependent upon the existing engine's applicable tier level and the tier level of the replacement engine. While estimates for total mitigated emissions may be calculated using manufacturer data for each engine, the following tables provide a quick estimate of the emissions reductions that may be reasonably expected with engine repowers. Note that this table refers to diesel-powered equipment. For repowers of other equipment type, use the emission factors found in Chapter 4 of the latest version of the Mobile Guide or engine manufacturer data if available.

Table 12-8. Uncontrolled to Tier 1, 2, 3, and 4 Diesel Engine Repower Emission Reduction Percentages

Model Year	Engine Size (hp)	Uncontrolled to Tier 1			Uncontrolled to Tier 2			Uncontrolled to Tier 3			Uncontrolled to Tier 4		
		NO_X	VOC [a]	PM	NO_X	VOC [a]	PM	NO_X	VOC [a]	PM	NO_X [b]	VOC [a]	PM
pre 1988	75 - 99	43%	31%	9%	56%	84%	50%	72%	90%	50%	98%	92%	98%
1988+	75 - 99	15%	0%	0%	35%	76%	40%	59%	85%	40%	96%	88%	97%
pre 1970	100 - 174	47%	48%	45%	64%	85%	60%	78%	91%	60%	98%	91%	97%
1970-71	100 - 174	43%	38%	36%	61%	81%	54%	76%	89%	54%	98%	89%	97%
1972-79	100 - 174	38%	32%	23%	58%	80%	44%	74%	88%	44%	97%	88%	96%
1980-84	100 - 174	33%	27%	23%	54%	78%	44%	72%	87%	44%	97%	88%	96%
1985-87	100 - 174	33%	23%	23%	54%	77%	44%	72%	86%	44%	97%	87%	96%
1987+	100 - 174	9%	0%	0%	39%	70%	20%	63%	82%	20%	96%	83%	95%
pre 1970	175 - 299	47%	34%	28%	64%	84%	73%	78%	90%	73%	98%	91%	97%
1970-71	175 - 299	43%	21%	16%	61%	81%	68%	76%	88%	68%	98%	89%	97%
1972-79	175 - 299	38%	12%	0%	58%	79%	62%	74%	87%	62%	97%	88%	96%
1980-84	175 - 299	33%	7%	0%	54%	77%	62%	72%	86%	62%	97%	87%	96%
1985-87	175 - 299	33%	1%	0%	54%	76%	62%	72%	85%	62%	97%	86%	96%
1987+	175 - 299	9%	0%	0%	39%	70%	45%	63%	82%	45%	96%	83%	95%
pre 1970	300 - 600	47%	34%	25%	65%	84%	72%	78%	90%	72%	98%	91%	97%
1970-71	300 - 600	43%	21%	12%	62%	81%	67%	76%	88%	67%	98%	89%	97%
1972-79	300 - 600	38%	12%	0%	59%	79%	61%	74%	87%	61%	97%	88%	96%
1980-84	300 - 600	33%	7%	0%	55%	78%	61%	72%	86%	61%	97%	87%	96%
1985-87	300 - 600	33%	1%	0%	55%	76%	61%	72%	85%	61%	97%	86%	96%
1987+	300 - 600	9%	0%	0%	40%	71%	45%	63%	82%	45%	96%	83%	95%

Source: SCAQMD, Off-Road Engine Mitigation Measures Table II-C. Calculated values use the average emission rates for each model year and engine size calculated by CARB and compared to the EPA emission standards for each tier. In instances where the EPA standards are provided for NO_X+NMHC, the source document assumes 95% NO_X and 5% NMHC.

a. Original source lists pollutant as ROG, which is assumed to be equivalent to VOC.

b. Assumes final NO_X emission standards.

Table 12-9. Tier 1, 2, and 3 to Higher Tier Engine Repower Reduction Percentages

Engine	**Tier 1 to Tier 2**			**Tier 1 to Tier 3**			**Tier 1 to Tier 4**			**Tier 2 to Tier 3**			**Tier 2 to Tier 4**			**Tier 3 to Tier 4**		
Size (hp)	**NO_X**	**VOC [a]**	**PM**	**NO_X**	**VOC [a]**	**PM**	**NO_X [b]**	**VOC [a]**	**PM**	**NO_X**	**VOC [a]**	**PM**	**NO_X [b]**	**VOC [a]**	**PM**	**NO_X [b]**	**VOC [a]**	**PM**
75 - 99	23%	76%	46%	52%	85%	46%	96%	88%	97%	38%	38%	0%	94%	50%	95%	91%	20%	95%
100 - 174	33%	70%	28%	59%	82%	28%	96%	83%	95%	39%	39%	0%	94%	43%	93%	89%	7%	93%
175 - 299	33%	76%	63%	59%	85%	63%	96%	86%	96%	39%	39%	0%	94%	43%	90%	89%	7%	90%
300 - 600	34%	76%	63%	59%	85%	63%	96%	86%	96%	38%	38%	0%	93%	42%	90%	89%	7%	90%

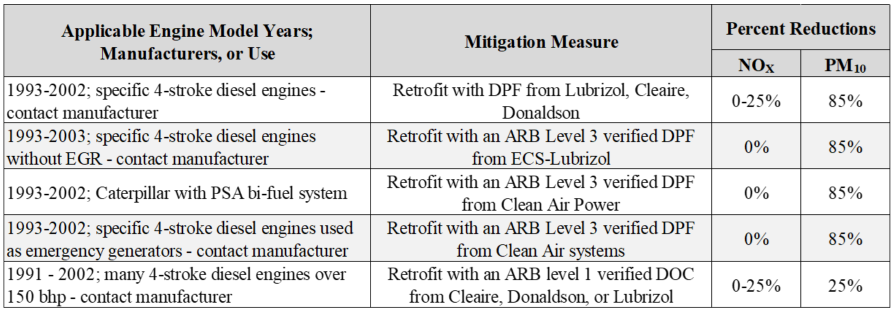
Source: SCAQMD, Off-Road Engine Mitigation Measures Tables II-C, II-D, and II-E. Calculated values use the average emission rates for each model year and engine size calculated by CARB and compared to the EPA emission standards for each tier. In instances where the EPA standards are provided for NO_X+NMHC, the source document assumes 95% NO_X and 5% NMHC.

a. Original source lists pollutant as ROG, which is assumed to be equivalent to VOC.

b. Assumes final NOX emission standards.

Equipment retrofitting involves the installation of emissions-control systems to existing equipment. The most common retrofits include diesel particulate filters (DPF) and diesel oxidation catalysts (DOC). Older equipment that does not already have a DPF or DOC installed will see a reduction in particulate and NOX emissions after this equipment is added. However, since these systems are designed and sized to an engine's exhaust flow rate, certain systems are compatible with only certain engines. Table 12-10 provides an estimate of the NOX and PM reductions expected for the installation of these systems on compatible engines. Contact the engine manufacturer to determine compatibility of any DPF and/or DOC prior to adding these measures to a mitigation plan.

Table 12-10. Heavy-Duty Equipment Retrofit Mitigation Measure Control Efficiencies



Applicable Engine Model Years; Manufacturers, or Use	Mitigation Measure	Percent Reductions	
		NO_X	PM_{10}
1993-2002; specific 4-stroke diesel engines - contact manufacturer	Retrofit with DPF from Lubrizol, Cleaire, Donaldson	0-25%	85%
1993-2003; specific 4-stroke diesel engines without EGR - contact manufacturer	Retrofit with an ARB Level 3 verified DPF from ECS-Lubrizol	0%	85%
1993-2002; Caterpillar with PSA bi-fuel system	Retrofit with an ARB Level 3 verified DPF from Clean Air Power	0%	85%
1993-2002; specific 4-stroke diesel engines used as emergency generators - contact manufacturer	Retrofit with an ARB Level 3 verified DPF from Clean Air systems	0%	85%
1991 - 2002; many 4-stroke diesel engines over 150 bhp - contact manufacturer	Retrofit with an ARB level 1 verified DOC from Cleaire, Donaldson, or Lubrizol	0-25%	25%

Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008.
DPF = Diesel Particulate Filter. DOC = Diesel Oxidation Catalyst.

12.4 Land Use

On-road vehicles serve as one of the greatest contributors to air pollutants in the world. In residential, commercial, and industrial areas where the population density is higher than average, the problem with vehicle emissions may be more apparent. To mitigate these emissions, a facility should implement transportation demand management measures (TDM) which work to reduce or eliminate trips or total vehicle miles traveled (VMT). Mitigation measures at commercial, industrial, and institutional worksites may be implemented when modification of the employee travel pattern is feasible. This means that the facility can provide transportation, implement compressed work schedules, or develop park-and-ride lots that accommodate its employees. For residential areas, building pedestrian facilities and bicycle paths that connect to an external network to encourage alternatives to vehicle use, though the effectiveness of these measures is minimal. Several studies have been conducted to determine the effectiveness of land use measures to reduce trips and VMT. Table 12-11 provides an estimate of the effectiveness of these measures.

Table 12-11. Land Use Mitigation Measure Commute Activity Reductions

	Mitigation Measure	Reduction in		Assumptions	Source
		Trips	VMT		
Commercial, Industrial, Institutional	Provide preferential carpool/vanpool parking spaces	0.5%	Same	SOV rate 9 1%, of which 50% is net 9 in trips (assumes shift to 2 person HOV), or 1% x 50% = 0.5%	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
	Implement a parking surcharge for single occupant vehicles	2.0%	1.5%	Surcharge of $3/day/employee SOV	Harvey, Greig, Pricing as a Transportation Control Measure, 1991
	Provide for shuttle/mini bus service	2.0%	Same	None	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
	Provide bicycle storage/parking facilities and shower/locker facilities.	1.0%	0.5%	Mode share 8 1% (trips 9 1%). Avg. bicycle trip length 50% of avg. work trip length (5 vs. 10 miles), or 1% 9 trips x 50% trip length = 0.5% 9 VMT	U.S. EPA, TCM Information Documents, 1991 and Calif. Energy Commission, Energy- Aware Planning Guide, 1993.
	Provide onsite child care centers	N/A	2.0%	7% use daycare, avg. work trip length 10 miles + 5 mile diverted linked trip to child care ctr. Reduces diverted linked trips (33% of VMT), or 7% x 33% 9 VMT . 2% 9 VMT	Calif. Energy Commission, Energy-Aware Planning Guide, 1993 and Association for Commuter Transportation, Case Study Series, 1990.
	Provide transit design features within the development	0.05%	0.1%	None	The Planning Center/JHK Assoc., TCM Effectiveness, 1992.
	Develop park-and-ride lots	10% per space occupied	89% per space occupied	4 mile avg. to lot, 11% of avg. home-work distance for park-n-riders (35 miles); 10% of VT to lot by bike/walk	Weant and Levinson, Parking, 1990.
	Employ a transportation/ rideshare coordinator	2.0%	Same	Exposes 25% to ridesharing; of 17% that take part, 50% 9 net trips (assumes SOV shift to 2-person HOV), or 25% x 17% x 50% 9 trips . 2% 9 trips and VMT	Multisystems, Paratransit Options, 1990.
	Implement a rideshare program	2.00%	Same	Availability of rideshare material and information 50% as effective as program with rideshare coordinator	See above
	Provide incentives to employees to rideshare or take public transportation	1.0%	Same	Subsidies/incentives 9 SOV by 2%, with 50% 9 net trips (assumes SOV shift to 2- person HOV), or 2% trips x 50% 9 trips = 1% trips and VMT	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
	Implement compressed work schedules	2.0%	Same	9/80 schedule 9 10% of trips, with 20% employee participation per day (staggered days off), or 10% 9 in trips x 20% = 2% trips and VMT	California Energy Commission, Energy-Aware Planning Guide, 1993.
	Implement telecommuting program	1.5%	3%	10% of employees 9 15% of trips, or 10% x 15% = 1.5% 9 trips. Avg. trip length for telecommuter 20 miles (200% of 10 mile avg.), or 1.5% 9 trips x 200% = 3% 9 VMT	Cambridge Systematics, TCM Info. Documents, 1991 and Kitamura, et al, Telecommuting & Travel Demand 1990.
Residential	Provide bicycle paths within major subdivisions that link to an external	0.1%	Negl.	None	MBUAPCD, 1991 AQMP Appendix A, TCM Measure 9
	Provide pedestrian facilities within major subdivisions	0.1%	Negl	None	MBUAPCD, 1994.

Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008. Table provides cited source's original references. SOV = Single-Occupancy Vehicle. HOV = High-Occupancy Vehicle. VMT = Vehicle Miles Traveled.

Guidance for the determination of emissions for on-road vehicle use is provided in chapter 5 of the latest version of the Mobile Guide. For projects that occur on-base, chapter 5 provides a simplified procedure that accounts for the typical vehicle mix found at Air Force installations. However, a more detailed procedure is provided if vehicle mix data is known. The estimated amount of mitigated emissions may be calculated using the appropriate percent reduction provided in Table 12-10.

12.5 Alternative Fuels

In addition to land use mitigation measures, on-road vehicle emissions may be further reduced by replacing vehicles that operate on gasoline and diesel fuel with alternative fuels. The most common alternatives include fully electric, hybrid, methanol, and compressed natural gas (CNG). The potential reduction in emissions depends on the number of conventional versus alternative fuel-powered vehicles as well as the total VMT. The estimated emissions reductions are provided in Table 12-12 by fuel and pollutant. Use the values provided in Table 12-12 and refer to Chapter 5 of the latest version of the Mobile Source Guide for guidance on estimating the potential reduction in emissions using alternative fuels in on-road vehicles.

Table 12-12. Alternative Fuel Use Emission Reductions

Mitigation Measure (original fuel type)	Emission Reductions vs. Conventional Vehicle						Assumptions	Source
	CO	NO_X	VOC	PM_{10}	$PM_{2.5}$	CO_2		
Electric Vehicles (gasoline or diesel)	100%	100%	100%	100%	100%	100%	No on-road emissions.	CEQA AIR QUALITY GUIDELINES, Monterey Bay Unified Air Pollution Control District -2008
Ultra Low-Emission Vehicles (gasoline)	50%	64%	82%	50%	50%	50%	None	CEQA AIR QUALITY GUIDELINES, Monterey Bay Unified Air Pollution Control District -2008 and The California Low-Emission Vehicle Regulations, With Amendments - August 7, 2012
Methanol Vehicles (gasoline)	---	64%	71%	---	---	---	85 (85% methanol, 15% gas)	CEQA AIR QUALITY GUIDELINES, Monterey Bay Unified Air Pollution Control District -2008
Liquid Propane Gas Vehicles (gasoline)	90%	64%	71%	90%	90%	25%	LPG vehicles are Low-Emission Vehicles (LEV). NOX, PM, and CO2 emission reductions are same as CNG.	CEQA AIR QUALITY GUIDELINES, Monterey Bay Unified Air Pollution Control District -2008
Compressed Natural Gas Vehicles (gasoline)	90%	35%	50%	90%	90%	25%	None	2021 Air Emissions Guide for Air Force Mobile Sources
B20 Diesel Vehicles (diesel)	0%	0%	0%	0%	0%	0%	None	2021 Air Emissions Guide for Air Force Mobile Sources

Note: This table compares running exhaust emission factors for Light-Duty Passenger Vehicles (up to 3,750 lb). Factors do not apply to retrofitted vehicles; these efficiencies will decrease over time.

Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008. Table provides cited source's original references.

12.6 References

Countess Environmental 2006, WRAP Fugitive Dust Handbook, WGA Contract No. 30204-111; 4001 Whitesail Circle, Westlake Village, CA 91361. September 7, 2006.

MBUAPCD 2008, Monterey Bay Unified Air Pollution Control District, CEQA Air Quality Guidelines, February 2008.

SCAQMD 2010, South Coast Air Quality Management District, Off-Road Engines Table II, May 2010

USEPA 2006a, "Compilation of Air Pollutant Emission Factors -Volume I (AP-42, Volume I), 5th Edition, Chapter 13.2.1, Miscellaneous Sources - Paved Roads," U.S. Environmental Protection Agency, November 2006

USEPA 2006b, " Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources (AP-42), Section 13.2.2, "Unpaved Roads," U.S. Environmental Protection Agency, November 2006

USEPA 2006b, " Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources (AP-42), Section 13.2.5, "Industrial Wind Erosion," U.S. Environmental Protection Agency, November 2006

APPENDIX A – EPA HAP LIST

CAS No.	Chemical/Compound
75070	Acetaldehyde
60355	Acetamine
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
79107	Acrylic Acid
107131	Acrylonitrile
107051	Allyl Chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl Chloride
92524	Biphenyl
117817	Bis(2-ethylhexyl)phthalate
542881	Bis(chloromethyl)ether
75252	Bromoform
106945	1-Bromopropane
106990	1,3-Butadiene
156627	Calcium Cyanamide
133062	Captan
63252	Carbaryl
75150	Carbon Disulfide
56235	Carbon Tetrachloride
463581	Carbonyl Sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane
7782505	Chlorine
79118	Chloroacetic Acid
532274	2-Chloroacetophenone
108907	Chlorobenzene
510156	Chlorobenzilate
67663	Chloroform
107302	Chloromethyl methyl ether
126998	Chloroprene
1319773	Cresylic Acid
95487	o-Cresol
108394	m-Cresol
106445	p-Cresol
98828	Cumene
94757	2,4-D
3547044	DDE

CAS No.	Chemical/Compound
334883	Diazomethane
132649	Dibenzofurans
96128	1,2-Dibromo-3-chloropane
84742	Dibutylphthalate
106467	1,4-Dichlorobenzene
91941	3,3-Dichlorobenzidene
111444	Dichloroethyl ether
542756	1,3-Dichloropropene
62737	Dichlorvos
111422	Diethanolamine
121697	N,N-Dimethylaniline
64675	Diethyl Sulfate
119904	3,3-Dimethoxybenzidine
60117	Dimethyl Aminoazobenzene
119937	3,3'-Dimethyl Benzidine
79447	Dimethyl Carbamoyl Chloride
68122	Dimethyl Formamide
57147	1,1-Dimethyl Hydrazine
13113	Dimethyl Phthalate
77781	Dimethyl Sulfate
534521	4,6-Dinitro-o-cresol
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane
122667	1,2-Diphenylhydrazine
106898	Epicholohydrin
106887	1,2-Epoxybutane
140885	Ethyl Acrylate
100414	Ethyl Benzene
51796	Ethyl Carbamate
75003	Ethyl Chloride
106934	Ethylene Dibromide
107062	Ethylene Dichloride
107211	Ethylene Glycol
151564	Ethylene Imine
75218	Ethylene Oxide
96457	Ethylene Thiourea
75343	Ethylidene Dichloride
50000	Formaldehyde
76448	Heptachlor
118741	Hexachlorobenzene
87683	Hexachlorobutadiene
77474	Hexachlorocyclopentadiene
67721	Hexachloroethane
822060	Hexamethylene-1,6-diisocyanate
680319	Hexamethylphosphoramide
110543	Hexane
302012	Hydrazine

CAS No.	Chemical/Compound
7647010	Hydrochloric Acid
7664393	Hydrogen Fluoride
123319	Hydroquinone
78591	Isophorone
58899	Lindane
108316	Maleic Anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl Bromide
74839	Methyl Chloride
74873	Methyl Chloroform
71556	Methyl Ethyl Ketone
60344	Methyl Hydrazine
74884	Methyl Iodide
108101	Methyl Isobutyl Ketone
624839	Methyl Isocyanate
80626	Methyl Methacrylate
1634044	Methyl tert Butyl Ether
101144	4,4-Methylene bis(2-Chloroaniline)
75092	Methylene Chloride
101688	Methylene Diphenyl Diisocyanate
101779	4,4'-Methylenedianiline
91203	Naphthalene
98953	Nitrobenzene
92933	4-Nitrobiphenyl
100027	4-Nitrophenol
79469	2-Nitropropane
684935	N-Nitroso-N-Methylurea
62759	N-Nitrosodimethylamine
59892	N-Nitrosomorpholine
56382	Parathion
82688	Pentachloronitrobenzene
87865	Pentachlorophenol
108952	Phenol
106503	p-Phenylenediamine
75445	Phosgene
7803512	Phosphine
7723140	Phosphorus
85449	Phthalic Anhydride
1336363	Polychlorinated Biphenyls
1120714	1,3-Propane Sultone
57578	beta-Propiolactone
123386	Propionaldehyde
114261	Propoxur
78875	Propylene Dichloride
75569	Propylene Oxide
75558	1,2-Proplenimine
91225	Quinoline

Appendix A – EPA HAP List (cont.)

CAS No.	Chemical/Compound
106514	Quinone
100425	Styrene
96093	Styrene Oxide
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79345	1,1,2,2-Tetrachloroethane
127184	Tetrachloroethylene
7550450	Titanium Tetrachloride
108883	Toluene
95807	2,4-Toluene Diamine
584849	2,4-Toluene Diisocyanate
95534	o-Toluidine
8001352	Toxaphene
120821	1,2,4-Trichlorobenzene
79005	1,1,2-Trichloroethane
79016	Trichloroethylene
95954	2,4,5-Trichlorophenol
88062	2,4,6-Trichlorophenol
121448	Triethylamine
1582098	Trifluralin
540841	2,2,4-Trimethylpentane
108054	Vinyl Acetate
593602	Vinyl Bromide
75014	Vinyl Chloride
75354	Vinylidene Chloride
1330207	Xylenes
95476	o-Xylene
108383	m-Xylene
106423	p-Xylene
---	Antimony Compounds
---	Arsenic Compounds
---	Beryllium Compounds
---	Cadmium Compounds
---	Chromium Compounds
---	Cobalt Compounds
---	Coke Oven Emissions
---	Cyanide Compounds [1]
---	Glycol Ethers [2]
---	Lead Compounds
---	Manganese Compounds
---	Mercury Compounds
---	Fine Mineral Fibers [3]
---	Nickel Compounds
---	Polycyclic Organic Matter [4]
---	Radionuclides (including Radon) [5]
---	Selenium Compounds

1. X'CN where X=H' or any other group where a formal dissociation may occur. For example KCN or Ca(CN)$_2$.
2. Includes mono- and di-ethers of ethylene glycol, diethylene glycol, and triethylene glycol R-(OCH$_2$CH$_2$)$_n$-OR', where:
   n = 1, 2, or 3,
   R = alkyl C7 or less; or R = phenyl or alkyl substituted phenyl,
   R' = H or alkyl C7 or less; or OR' consisting of carboxylic acid ester, sulfate, phosphate, nitrate, or sulfonate
3. Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.
4. Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C.
5. A type of atom which spontaneously undergoes radioactive decay.