

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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AIR EMISSIONS GUIDE FOR AIR FORCE TRANSITORY SOURCES

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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
AFCEC	Air Force Civil Engineer Center
AGE	Aerospace Ground Equipment
ALAPCO	Association of Local Air Pollution Control Officials
AMX	Aircraft Maintenance Squadron
BEE	Bioenvironmental Engineer
BOOS	Burners Out Of Service
CAIR	Clean Air Interstate Rule
CAS	Chemical Abstracts Service
CONUS	Continental United States
DAC	Defense Ammunition Center
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
HAZMAT	Hazardous Materials
HEPA	High Efficiency Particulate Air
HVAC	Heating, Ventilating, and Air Conditioning
ICAO	International Civil Aviation Organization
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
OCONUS	Outside Continental United States
OTAG	Office of Transportation Quality
PEMS	Predictive Emission Monitoring System
RAP	Reclaimed Asphalt Pavement
SAR	Second Assessment Report
SAW	Submerged Arc Welding
SIC	Standard Industrial Classification
SIP	State Implementation Plan
SMAW	Shielded Metal Arc Welding
STAPPA	State and Territorial Air Pollution Program Administrators

TAR	Third Assessment Report
USAF	United States Air Force
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
AFB	Air Force Base
AFI	Air Force Instruction
AFRL	Air Force Research Laboratory
AGSE	Aerospace Ground Support Equipment
APU	Auxiliary Power Unit
AVGAS	Aviation Gasoline
BMP	Best Management Practices
BSFC	Brake-Specific Fuel Consumption
CAA	Clean Air Act
CAAA	Clean Air Act Amendments (of 1990)
CBPO	Consolidated Base Personnel Office
CE	Civil Engineering
CEMS	Continuous Emission Monitoring System
CEV	Civil Engineering Environmental
CFC	Chlorofluorocarbon
CFR	Code of Federal Regulations
CFRM	Continuous Flow Rate Monitor
CI	Compression Ignition
CNG	Compressed Natural Gas
DCA	Defense Commissary Agency
DESC	Defense Energy Support Center
DLA	Defense Logistics Agency
DNA	Defense Nuclear Agency
DOD	Department of Defense
DOE	Department of Energy
EA	Environmental Assessment
EDMS	Emissions and Dispersion Modeling System
EDP	Electrodeposition
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
EPAct	Energy Policy Act
ERC	Emission Reduction Credit
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
FFV	Flexible Fuel Vehicles
FGD	Flue Gas Desulphurization
FGR	Flue Gas Recirculation
FT	Fischer-Tropsch
GHG	Greenhouse Gas
GMAW	Gas Metal Arc Welding
GOV	Government Owned Vehicles
GSA	General Services Administration
GSE	Ground Support Equipment
GVW	Gross Vehicle Weight
HBFC	Hydrobromofluorocarbons
HC	Hydrocarbon
HCFC	Hydrochlorofluorocarbons
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
ICAO	International Civil Aviation Organization
IPCC	Intergovernmental Panel on Climate Change
IRP	Installation Restoration Program
LDF	Liquid Drift Factors
LEL	Lower Explosive Limit
LFB	Low Flyby
LFG	Landfill Gas
LFP	Low Flight Pattern
LGRVM	Vehicle Management Flight Vehicle Maintenance
LNB	Low NOX Burner

LPG	Liquefied Petroleum Gas
LTO	Landing and Takeoff
MB	Material Burned
MC	Medium Cure
MEK	Methyl Ethyl Ketone
Mg	Megagram(s) [i.e., metric ton]
mg	Milligram(s)
MIDAS	Munitions Items Disposition Action System
MEK	Methyl Ethyl Ketone
MM	Minutemen Missiles
MMBtu	Million British Thermal Units
Mn	Manganese
MPF	Military Personnel Flight
MPO	Metropolitan Planning Office
MSDS	Material Safety Data Sheet
MSW	Municipal Solid Waste
NACAA	National Association of Clean Air Agencies
NDI	Non-destructive Inspection
NEI	National Emission Inventory
NMHC	Non-methane Hydrocarbons
NMOC	Non-methane Organic Compounds
NSCR	Nonselective Catalytic Reduction
NSPS	New Source Performance Standards
NSR	New Source Review
OB/OD	Open Burning/Open Detonation
OBODM	Open Burning/Open Detonation Model
OCA	Off-Site Consequences Analysis
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
PEMS	Predictive Emission Monitoring System
PM	Particulate Matter – Aerodynamic diameter unspecified
PM10	Particulate Matter – Aerodynamic diameter < 10 micrometers
PM2.5	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
POM	Polycyclic Organic Matter
POTW	Publicly Owned Treatment Works
POV	Privately Owned Vehicles

PTE	Potential-To-Emit
RC	Rapid Cure
REO	Regional Environmental Offices
REEDM	Rocket Exhaust Effluent Diffusion Model
RMP	Risk Management Plan
RVP	Reid Vapor Pressure
SC	Slow Cure
SCC	Source Classification Code
SCR	Selective Catalytic Reduction
SI	Spark Ignition
SOCMI	Synthetic Organic Chemical Manufacturing Industry
SVE	Soil Vapor Extraction
TCLP	Toxicity Characteristics Leaching Procedure
TDS	Total Dissolved Solids
TGO	Touch-and-Go
THC	Total Hydrocarbons
TIM	Time In Mode
TLG	Total Landfill Gas
TNMOC	Total Non-methane Organic Compounds
T.O.	Technical Order
TOC	Total Organic Compounds
TRI	Toxic Release Inventory
TSD	Treatment, Storage, & Disposal
TSP	Total Suspended Particulate
ULSD	Ultra Low Sulfur Diesel
U.S.	United States
UST	Underground Storage Tanks
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)
µm	Micrometer(s)
A-hr	Ampere-hours
Btu	British Thermal Unit
°C	Degrees Celsius
CH ₄	Methane
CO	Carbon Monoxide
Co	Cobalt
Cr	Chromium
dscf	Dry Standard Cubic Feet
dscfm	Dry Standard Cubic Feet per Minute
EtO	Ethylene Oxide
°F	Degrees Fahrenheit
ft.	Foot (Feet)
g/L	Grams per Liter
gal	Gallon(s)
HCl	Hydrochloric Acid
hp	Horse Power
hr	Hour(s)
kW	Kilowatt(s)
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 ₂ O	Nitrous Oxide
NO ₂	Nitrogen Dioxide
NO _x	Nitrogen Oxides
Pb	Lead
ppm	Parts per Million
ppmv	Parts per Million by Volume
psi	Pounds per Square Inch
°R	Degrees Rankin
scf	Standard Cubic Foot
SO ₂	Sulfur Dioxide
SO _x	Sulfur Oxides

tpy	Tons per Year
yr	Year(s)

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1 INTRODUCTION

1.1 Background and Purpose

In order to better control hazardous emissions and reduce them, the Clean Air Act (CAA) was established in 1970 as a federal law to reduce emissions of harmful pollutants. The U.S. Environmental Protection Agency (EPA) is responsible for protecting the public and environment by establishing standards aimed at reducing pollutant emissions. The EPA has established National Ambient Air Quality Standards (NAAQS) which require facility managers to know at all times if they are in compliance with air 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 given 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 include 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 located on an Air Force Installation, to include: bulk storage tank cleaning, seasonal equipment, fuel spills, hot mix asphalt plants, prescribed burning, wild fires, all sources associated with construction, and all sources associated with site restoration/remediation. Any questions concerning this document, calculation methodologies for sources not provided here, and/or requests for additional information pertaining to Air Force air emission inventories should be directed to the Air Quality Subject Matter Expert; AFCEC, Compliance Technical Support Branch; 250 Goodrich Drive, Building #1650; San Antonio, TX 78226.

1.2 Transitory Sources

Transitory sources are non-routine and/or seasonal sources (may be stationary, mobile or neither) that are short-term in nature. While historically transitory source 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 action under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA); National Environmental Policy Act (NEPA), General Conformity, etc.

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 installations include: bulk storage tank cleaning, fuel spills, prescribed burning, wild fires, 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 installations 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. Non-road sources include a multitude of equipment used for construction, agriculture, recreation, and many other 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 Applicable Air Quality Related Regulations

1.3.1 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 Hazardous Air Pollutants (HAP) 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 Clean Air Act known as 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 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. To learn if a source is considered a “major source,” more details can be looked up under the Clean Air Act Amendment of 1990 after reviewing an emissions inventory. Also under the CAA, Section 176(c) of the CAA prohibits federal activities from taking various actions in nonattainment or maintenance areas unless they first demonstrate conformity with their respective SIP.

1.3.1.1 New Source Review (NSR)

The New Source Review (NSR) permitting program was established as part of the 1977 CAA amendments in an effort to ensure that air quality is not significantly degraded as a result of new construction or modifications at existing facilities. The NSR permits establish how a source is to be operated, its emission 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 for pollution located 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 tons per year, including fugitive emissions, are regarded as PSD major sources. Sources which do not fall into one of the 28 categories are regarded as PSD major sources if they emit 250 tons per year, excluding fugitive emissions. Typically, at an Air Force installation, the only two sources likely to be on base that fall into one of these categories are fossil fuel boilers greater than 250 MMBtu/hr heat input and petroleum storage units with a capacity exceeding 300,000 barrels. 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 for pollution 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 stringent. Additionally, since the construction is to take place in a nonattainment area, part

of the nonattainment NSR program requires some form of emission offsets. These offsets are reductions in emissions from existing sources in the vicinity of the proposed construction which are greater than the emissions increase from the new source to provide a net air quality benefit.

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

1.3.1.2 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** first establishes if a full-scale conformity determination is required and, if it is, a **conformity determination** 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 National Environmental Policy Act (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 alternative.

1.3.2 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 as many as three levels of analysis:

- **Categorical Exclusion Determination** – a proposed action may be categorically excluded from a detailed environmental analysis if the action meets certain criteria which a previous agency has previously determined to have no significant environmental impact.
- **Environmental Assessment (EA)** – a proposed action not categorically excluded must be evaluated to determine if undertaking would significantly affect the environment. If no, 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 is allowed to decide on the proposed action.

1.3.3 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). Air Force 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.

1.4 Pollutants

The emissions of concern from transitory sources include HAPs, criteria pollutants, and greenhouse gas emissions. With the most updated data, and the right calculation method, pollutants can be estimated from each source to determine if a facility is considered a “major source”. A Source that is defined as “major” by the EPA is a source that emits 10 tons per year of any of the listed toxic air pollutants, or 25 tons per year of a mixture of air toxics. These sources may release air toxics from equipment leaks, when materials are transferred from one location to another, or during discharge through emission stacks or vents.

1.4.1 Criteria Pollutants

In 1971, the EPA established National Ambient Air Quality Standards (NAAQS) for six pollutants which are termed criteria pollutants. The Environmental Protection Agency (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]):

- Includes the very fine dust, soot, smoke, and droplets formed from chemical reactions and incomplete burning of fuels.
- The fine particles can get deep into the lungs, causing increased respiratory illnesses and tens of thousands of deaths each year.
- Particulate matter is defined as any particle with an equivalent diameter of ≤ 10 microns (**PM₁₀**) and is further subdivided to include a separate standard for particles with an equivalent aerodynamic diameter of ≤ 2.5 microns (**PM_{2.5}**).

Ground-Level Ozone (O₃):

- A primary component of smog which can cause human health problems and damage forests and agricultural crops.
- Repeated exposure to ozone can make people more susceptible to respiratory infections and lung inflammation.
- Though there is a NAAQS, **ozone is not emitted directly into the air.**
- Two types of chemicals that are the main ingredients (precursors) in forming ground-level ozone
 - **Volatile organic compounds (VOCs):** Defined as “any compound of carbon, excluding carbon monoxide, carbon dioxide, carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions” (40 CFR 51.100). Sources include vehicles burning gasoline, petroleum refineries, chemical manufacturing plants, industrial plants, solvents used in paints, and an assortment of consumer and business products containing VOCs.
 - **Nitrogen oxides (NO_x):** Produced when cars and other sources like power plants and industrial boilers burn fuels such as gasoline, coal, or oil. Nitrogen Oxides produce a reddish-brown tint to smog.

Carbon Monoxide (CO):

- Produced when fossil fuel burns incompletely due to insufficient oxygen.
- Wood, coal, and charcoal fires and gasoline engines always produce carbon monoxide.
- Nationally, and particularly in urban areas, the majority of CO air emissions are from mobile sources.
- Can cause harmful health effects by reducing oxygen delivery to the body's organs (like the heart and brain) and tissues.

Sulfur Oxides (SO_x):

- A group of highly reactive gases known as “oxides of sulfur”.
- Emissions are produced from fossil fuel combustion at power plants (73%) and other industrial facilities (20%).
- SO₂ is linked to a number of adverse effects on the respiratory system.
- SO₂ in the ambient air is just one of several oxides of sulfur that contribute to air quality issues.

Nitrogen Oxides (NO_x):

- A subgroup of nitrogen oxides, NO₂ is the component of greatest interest and the indicator for the larger group of nitrogen oxides.
- NO₂ forms quickly from emissions from vehicles, power plants, and off-road equipment.
- Also contributes to the formation of ground-level ozone, and fine particle pollution.
- Linked with a number of adverse effects on the respiratory system.

Lead (Pb):

- A metal found naturally in the environment as well as in manufactured products.
- Prior to 1980 the major sources of Pb were cars and trucks; as a result, the EPA removed Pb from motor vehicle gasoline, resulting in a 95% decline between 1980 and 1999.
- Today, the major sources of Pb are ore and metals processing (e.g. lead smelters) and leaded aviation gasoline.
- 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 is commonly provided in both the criteria pollutant and speciated HAPs tables within this document. Care should be taken to avoid the overestimation of this pollutant from duplication of these emission factors. For a current list of the NAAQS for the criteria pollutants, refer to the Code of Federal Regulations (CFR), specifically, 40 CFR 50.

Since ozone is not directly emitted into the air, but rather is created through photochemical reactions involving nitrogen oxides (NO_x) and VOCs, and because PM may be the result of the release of primary pollutants or the formation of secondary pollutants, this document provides emission factors for a list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of “criteria pollutants” for emissions inventory purposes includes the following:

- CO
- NO_x
- PM₁₀
- PM_{2.5}
- SO_x
- VOCs
- Pb

1.4.2 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 which includes 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) in November 2004 (69FR69320), and Methyl Ethyl Ketone (MEK) in December 2005 (70FR75047).

1.4.3 Greenhouse Gases

Global climate change is becoming one of the most important issues of the 21st century. Some GHGs such as carbon dioxide occur naturally and are emitted to the atmosphere through natural processes and human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities. The principal GHGs that enter the atmosphere because of human activities are carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), and fluorinated gases.

CO₂ is the primary greenhouse gas emitted through human activity, accounting for 82% of all U.S. greenhouse gas emissions from human activities. CO₂ enters the atmosphere primarily through the burning of fossil fuels and engines used for transportation, though several industrial processes also emit CO₂. CO₂ is also removed from the atmosphere (or “sequestered”) when it is absorbed by plants as part of the biological carbon cycle. CH₄ is emitted during the production and transport of coal, natural gas, and oil. CH₄ emissions also result from livestock and other agricultural practices and by the decay of organic waste in municipal solid waste landfills. N₂O is emitted during agricultural and industrial activities, as well as during combustion of fossil fuels and solid waste.

Greenhouse gases 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, which is typically 100 years. The higher the GWP, the greater the potential for the gas to trap heat, and the more harmful the gas is considered. CO₂ is used as the baseline gas and assigned a GWP of 1. Emissions of CH₄ and N₂O may be converted into equivalent CO₂ (CO₂e) by taking the product of each GHG emission and its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several greenhouse gases.

1.5 Emissions Inventory Methodologies

Transitory sources have similar characteristics to stationary sources and share the same methodology for calculating emissions. The preferred method for estimating emissions is through continuous emissions monitoring or stack sampling, though this method may not be feasible as it is expensive to perform. When data from source-specific emission testing or continuous emission monitoring is unavailable, emissions may be estimated using mass balance calculations, existing emissions models, or calculations involving established emission factors.

An emission factor is a value relating the amount of pollution generated to the amount of raw material processed or number of product units produced. It is a representative value that relates the quantity of a pollutant released into the atmosphere with an activity associated with the release of that pollutant. Many emission factors found in this document were taken from the EPA publication: *Compilation of Air Pollutant Emission Factors* (AP-42). The emission factors provided in AP-42 are assigned a data quality rating from “A” through “E,” with “A” being the best quality. This 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 emission factors may be available from other sources, most notably the California Air Resource Board (CARB). If an emission factor 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. Alternative emission factors, such as those requested by state and local air regulators, may be used as long as the alternative emission factor is submitted and approved by the air quality Subject Matter Expert (SME).

The general equation for emission estimation using an emission factor is shown below in Equation 1-1.

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

Equation 1-1

Where,

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

Note that 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 time period, an average efficiency is used to account for routine operations. Not all processes use an emissions control device.

1.6 Document Organization

This document is organized into chapters which 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, but the intent is to consider sources usually associated with a particular facility/activity/process. This document specifically addresses transitory sources of air emissions. Guidance for addressing mobile or stationary sources of air pollutants may be found in the Air Force Mobile Guide or Air Force Stationary Guide respectively.

1.7 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, and 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

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2 BULK STORAGE TANK CLEANING (TCRL)

➤ Fugitive Source

2.1 Introduction

Storage tanks located on Air Force installations are used for storage of materials, commonly including fuels such as JP-8, Jet A, MOGAS, and diesel, or even asphalt or 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 Environmental Protection Agency (EPA), an underground storage tank (UST) is defined as a tank or piping system that has 10% or more of its combined volume underground, while above ground storage tanks (AST) have more than 90% of their volume above the ground surface.

All storage tanks are occasionally emptied and cleaned for activities such as service changes, scheduled maintenance, and inspections. Emissions result from vapor displacement, from 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, while the remaining 20% is composed of VOCs which 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.

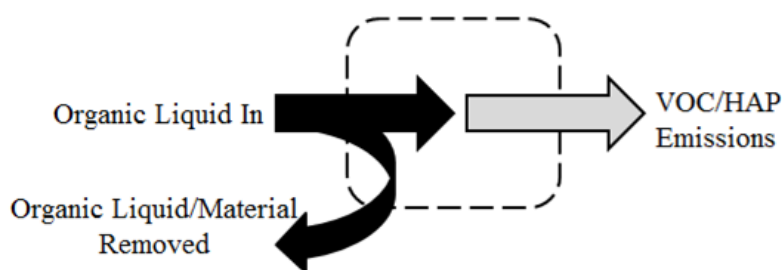


Figure 2-1. Simplified Bulk Storage Tank Cleaning Control Volume

There are several types of roof designs for storage tanks which influence the amount of emissions released from tank use, though have no effect on the amount of emissions released during tank cleaning. Calculation of working and storage losses is performed by the EPA's TANKS program. Refer to the "Storage Tanks" chapter of the Stationary Guide for additional information.

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 application of solvents
- 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 retested 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.

2.2 NESHAP Applicability

There are several National Emission Standards for Hazardous Air Pollutants (NESHAPs) applicable to storage tanks. These standards are provided in 40 CFR 63 OO, WW, EEEE, and CCCCCC, and detail the requirements for the operation of storage tanks and any control devices which may be required during their use. Though these standards do not directly apply to the process of cleaning storage tanks, it is stated that access to storage tank interiors is limited to only a few instances including the inspection, maintenance, and cleaning. Refer to these subparts for more information regarding the standards required 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 to 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 recovering 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 is capable of recovering 99% of the VOCs from the inlet gas stream.

2.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. Emissions from bulk tank cleaning operations occur from tank degassing and from the evaporation of VOCs in the

sludge and solvents applied, if any. Note that there are different processes and types of equipment used in cleaning storage tanks. Emissions from storage tank cleaning may be greatly reduced based on the procedures used. Contact the personnel responsible for the cleaning of the storage tank(s) throughout the year to set up an accurate emissions profile from this process. The following steps are recommended for a “typical” storage tank cleaning.

2.4.1 Emissions Calculation from Degassing and Clingage

According to the EPA, emissions from degassing storage tanks may be approximated as follows:

- For a fixed roof tank, calculate emissions from one turnover with the turnover factor (K_n)=1 to account for vapors displaced during filling and then add the emissions from one turnover calculated as if the tank had a floating roof to account for clingage.
- For a floating roof tank, calculate emissions for one turnover then add the emissions from the tank assuming it has a fixed roof with a height equal to the height of the legs to approximate the vapor displaced from the space under the floating roof.

Emissions may be calculated using TANKS which is a program based on the emission estimation procedures from Chapter 7 of EPA’s *Compilation of Air Pollutant Emission Factors* (AP-42). In order to calculate emissions from bulk storage tank cleaning operations, characteristics of the tank need to be noted such as tank capacity, diameter, and other variables. Weather data plays an important factor for emissions because they are dependent on variables such as temperature and solar insulation. However, rather than use TANKS for emissions calculations, a simple method for calculating emissions has been developed. Emissions from one turnover during cleaning may be described as follows:

$$L_C = L_W + L_F$$

Equation 2-1

Where,

- L_C = Total losses associated with storage tank cleaning (lb/yr)
- L_W = Withdrawal/clingage losses associated with storage tank cleaning (lb/yr)
- L_F = Filling losses associated with storage tank cleaning (lb/yr)

The clingage losses are a function of the tank dimensions, the density of the stored liquid, and the “clingage factor”, which is a statistical average of the amount of liquid residue that adheres to the inner surface of the tank. Clingage loss is calculated as follows:

$$L_W = 0.132 \times D \times \left(h + \frac{D}{2} \right) \times C_S \times W_L$$

Equation 2-2

Where,

- L_w** = Clingage loss from storage tanks (lb)
0.132 = Equation constant (10³ft³ gal/ft² bbl)
D = Tank diameter (ft)
h = Deck leg height (ft)
C_s = Clingage factor (bbl/10³ ft³). **Use 0.0015 for single component stock.**
W_L = Average liquid density (lb/gal)

Derivation of Equation 2-2 was accomplished through the following steps: According to AP-42, the working losses are calculated as follows:

$$L_W = \frac{(0.943) \times Q \times C_S \times W_L}{D} \times \left[1 + \frac{N_C F_C}{D} \right] \quad (\text{Section 7.1.3.2.1 AP-42, Equation 2-4})$$

Given that a fixed-roof tank is the least expensive and considered the minimum acceptable equipment, the assumption is that most on-base storage tanks are fixed roof types. According to AP-42, the number of fixed roof support columns for fixed roof and external floating roof tanks is 0. Equation 2-4 may be simplified as shown:

$$L_W = \frac{(0.943) \times Q \times C_S \times W_L}{D}$$

The equation constant in this equation is a function of the shell area and number of turnovers as shown:

$$\pi \times D \times h \left(\frac{ft^2}{ft^2} \right) \times \left[\frac{Q(bbl)}{\frac{\pi \times D^2 \times h(ft^2)}{4}} \times \frac{1 ft^2}{0.178 bbl} \right] \times \frac{42 gal}{1 bbl} \times \frac{10^3 ft^2}{1000 ft^2} = 0.943 \times \frac{Q}{D} \left(\frac{10^3 ft^2 gal}{bbl} \right)$$

However, for one turnover, the bracketed term in the equation above is equal to 1. The equation above, and Equation 2-4 from AP-42, may be simplified and combined as follows:

$$L_W = \pi \times D \times h \times 0.042 \times C_S \times W_L$$

However, this equation does not account for the circular sides of a cylindrical tank shell. Adding this term to the above equation gives:

$$L_W = \pi \times D \times h \times 2 \times \pi \times \frac{D^2}{4} \times 0.042 \times C_S \times W_L$$

This equation may now be simplified to Equation 2-2.

Once the clingage loss is determined, the filling loss must be calculated. This factor is estimated using the tank dimensions, the throughput, and the properties of the organic liquid as shown:

$$L_F = 0.00014 \times M_V \times P_V \times (D^2 \times h)$$

Equation 2-3

Where,

- L_F** = Filling loss from storage tanks (lb)
0.00014 = Equation constant (lb-mol/psia ft³)
M_V = Vapor molecular weight (lb/lb-mol)
P_V = Vapor pressure at daily average liquid surface temperature (psia)
D = Tank diameter (ft)
h = Deck leg height (ft)

Equation 2-3 was derived using the tank volume and instruction from AP-42 as shown:

$$L_F = 0.0010 \times M_V \times P_V \times Q \times K_N \times K_P \quad (\text{Section 7.1.3.1.2 AP-42, Equation 1-29})$$

Note that emissions here are designated as L_F for “filling losses” to reduce confusion though AP-42 designates this as a working loss, L_w.

The throughput, Q, is a function of the tank volume and can be expressed as:

$$Q = \left[\pi \times \frac{D^2}{4} \times h \right] (ft^3) \times 0.178 \left(\frac{bbl}{ft^3} \right) = 0.14 \times D^2 \times h$$

Since the filling loss calculation involves only one turnover, the saturation factor, K_N, is equal to 1. Also, AP-42 states that the working loss product factor, K_P, is 1 for organic liquids excluding crude oil. Substituting these values and the throughput equation above into equation 1-29 from AP-42, reduces to Equation 2-3.

2.4.2 Emissions Calculation from Sludge Handling

Emissions from the handling of sludge from storage tanks are the sum of the VOCs which evaporate from the sludge itself as well as the evaporation of the solvents used to remove the sludge, if any. The procedures for estimating these emissions are described below.

2.4.2.1 Emissions From the Remaining Sludge

Over time, material in the organic liquid stored in a tank will settle. The settling particulate combines with water and forms a substance referred to as sludge. Sludge is the result of oxidized hydrocarbons in the organic liquid and may be difficult to remove. The EPA states that sludge is typically 80% to 90% water by weight (USEP 2012). A conservative approach is to assume that 80% is water and the remaining 20% is composed of VOCs. Ideally, when performing storage

tank cleaning, the actual VOC content and density of the sludge may be measured and used for emissions estimates. The total VOCs emitted from the sludge removed from the tank is estimated as follows:

$$E(\text{Sludge})_{\text{voc}} = W \times \frac{WP_{\text{voc}}}{100}$$

Equation 2-4

Where,

- E(Sludge)_{voc}** = VOC emissions from the handling of wet sludge (lb/yr)
W = Mass of the wet sludge (lb/yr)
WP_{voc} = Weight percent of the VOC in the sludge (%). **Use 20% if unknown.**
100 = Factor converting percent to a fraction (%)

The mass of the sludge may be estimated using the volume and specific gravity of the sludge. This is an approximation that may be used if the mass of the wet sludge is unknown and assumes a uniform density and distribution across the tank floor. If the specific gravity or density of the sludge is unknown, it may be approximated to be equal to water. This assumes a low-solids content and is an approximation. The mass is calculated as follows:

$$W = S.G. \times 62.3 \times (V_S - V_D)$$

Equation 2-5

Where,

- S.G.** = Sludge specific gravity. **Use a value of 1 if unknown.**
62.3 = Density of water at 70°F (lb/ft³)
V_S = Volume of the sludge (ft³)
V_D = Volume of sludge removed and disposed (ft³)

The configuration of the tank (i.e., horizontal vs vertical) determines the calculation of the volume of the sludge. The thickness of the sludge, which is the height of the sludge from the tank floor, may be estimated and the volume in both a vertical and horizontal cylindrical tank is calculated using the appropriate equation below:

$$V_S = \pi \times \frac{D^2}{4} \times t \quad \text{Vertical Tank}$$

$$V_S = \frac{D^2}{4} \times \cos^{-1} \left(\frac{D/2 - t}{D/2} \right) - \left(\frac{D}{2} - t \right) \times \sqrt{D \times t - t^2} \quad \text{Horizontal Tank}$$

Where,

- D** = Tank diameter (ft)
t = Sludge thickness (ft)

2.4.2.2 Emissions from Degreasing

Some storage tank cleaning operations may require the use of solvents to break up the sludge remaining in the tank. The solvents used may simply be heated and/or high pressure water or a commercial degreasing solution composed of VOCs and/or HAPs. Most operations which use solvents for sludge removal have a delivery and vacuum system that actively measures the solvent added and removed. Emissions from the application of solvents are estimated using a mass balance as shown:

$$E_{Pol} = (M_A - M_R) \times \frac{WP_{Pol}}{100}$$

Equation 2-6

Where,

- E_{Pol}** = Annual emissions of pollutant (lb/yr)
- M_A** = Mass of pollutant applied (lb/yr)
- M_R** = Mass of pollutant recovered (lb/yr)
- WP_{Pol}** = Weight percent of pollutant in the solvent (%)
- 100** = Factor for converting percent to a fraction (%)

2.4.3 Emissions from Landing Floating Roof Storage Tanks

In addition to storage tank cleaning, it is also important to calculate emissions resulting from the landing of a floating roof storage tank on the tank legs. The landing of a floating roof on the tank legs occurs during a change of product service and during some maintenance activities. The total losses from roof landings, as detailed in Chapter 7 of AP-42, is the sum of the standing idle losses and filling losses from each landing event as shown:

$$L_{TL} = L_{SL} + L_{FL}$$

Equation 2-7

Where,

- L_{TL}** = Total losses from roof landing (lb/landing episode)
- L_{SL}** = Standing idle loss during roof landing (lb/landing episode)
- L_{FL}** = Filling loss during roof landing (lb/landing episode)

When a floating roof is landed, the breather vents are activated to equalize the pressure within the tank and prevent tank damage. The breather vent remains open until the roof is floated again. As long as the roof is landed, vapor may continue to be emitted into the atmosphere through the vent resulting in losses referred to as standing idle losses. Standing idle losses are calculated as follows:

$$L_{SL} = 0.024 \times n_d \times \left(\frac{P \times V_v}{R \times T} \right) \times M_v$$

Equation 2-8

Where,

- 0.024** = Equation constant. Description of its derivation is described below.
- n_d** = Number of days the tank stands idle per landing episode (1/landing episode)
- P** = True vapor pressure of stock liquid (psia)
- V_v** = Volume of the vapor space (ft³)
- R** = Ideal gas constant, 10.731 (psia-ft³/lb mole-°R)
- T** = Temperature (°R). °R = °F + 460
- M_v** = Vapor molecular weight (lb/lb-mole)

The equation constant, 0.024, is the product of the vapor space expansion factor, K_E , and the saturation factor, K_S . For enhanced accuracy, these values may be calculated using equations from AP-42. K_E is calculated using Equation 1-5 from AP-42, while K_S is estimated using equation 1-20. However, for simplification, the value for K_E is assumed to be 0.04 per equation 1-6. Also, AP-42 states that K_S is assumed to be less than or equal to the saturation factor during filling which is related to the liquid remaining in the tank after draining, known as the liquid heel. For conservative estimation, the tank is assumed to have a full liquid heel, which results in a saturation factor of 0.60. Substituting the K_E and K_S values provided, the following equation simplifies to Equation 2-8.

$$L_{SL} = n_d K_E \left(\frac{P V_v}{R T} \right) M_v K_S \quad (\text{Section 7.1.3.2.2 of AP-42, Equation 2-16})$$

The filling loss, L_{FL} , from the landing of a floating roof tank is the result of emissions as the tank is refilled and the liquid reaches the level of the floating roof. This value is calculated using Equation 2-26 from AP-42 as shown:

$$L_{FL} = \left(\frac{P \times V_v}{R \times T} \right) \times M_v \times S$$

Equation 2-9

Where,

- S** = Filling saturation factor. 0.60 for a full liquid heel and 0.50 or a partial heel

2.4.4 HAP Emissions

HAPs are calculated in a similar manner as VOCs by taking the weight percent HAPs in the emitted VOCs as shown:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

Equation 2-10

Where,

E_{HAP} = Annual HAP emissions (lb/yr)

E_{VOC} = Total annual VOC emissions (lb/yr). Note that this is the total from degassing and sludge handling

WP_{HAP} = Weight percent of the HAP in the VOC (%)

2.5 Information Resources

For a complete list of storage tanks located on base, as well as information concerning each tank's contents, contact the Base Supply Fuels Management or Civil Engineering Liquid Fuels shop. These offices should also be able to provide tank characteristic data needed to run the TANKS model including tank type, dimensions, volume, paint color, and tank condition. For information pertaining to fuel service stations, it may be necessary to also contact the service station supervisor.

2.6 Example Problem

Anytown AFB is looking at calculating emissions from the cleaning of one of their diesel storage tanks located on base. The tank is a fixed-roof, vertical, above ground tank with a diameter of 40 feet, and a deck leg height of 8 feet. It is estimated that approximately 6 inches of sludge caked the tank floor and solvent was applied to remove it. The solvent applied was CS-1 and is composed of 50% by weight inorganic HAPs. A total of 120 lb of the solvent was applied and 102 lb were recovered. Calculate the total VOC and HAP emissions from the cleaning of this tank. (Assume the diesel density, vapor molecular weight, and vapor pressure, are 7.14lb/gal, 130 lb/lb-mol, and 0.009 psia respectively. Also, assume total HAP weight percent in liquid and vapor phase are 1.1% and 25.2% respectively.)

Step 1 – Calculate the clingage loss. Using the data from the problem statement and Equation 2-2, the clingage loss is calculated as follows:

$$L_W = 0.132 \times D \times \left(h + \frac{D}{2} \right) \times C_S \times W_L$$

$$L_W = 0.132 \frac{10^3 ft^3 gal}{ft^2 bbl} \times 40 ft \times \left(8 ft + \frac{40 ft}{2} \right) \times 0.0015 \frac{bbl}{10^3 ft^3} \times 7.14 \frac{lb}{gal}$$

$$L_W = 0.132 \frac{10^3 ft^3 gal}{ft^2 bbl} \times 40 ft \times (28 ft) \times 0.0015 \frac{bbl}{10^3 ft^3} \times 7.14 \frac{lb}{gal}$$

$$L_W = 0.132 \frac{10^3 ft^3 gal}{ft^2 bbl} \times 1120 ft^2 \times 0.0015 \frac{bbl}{10^3 ft^3} \times 7.14 \frac{lb}{gal} = \mathbf{1.58 lb}$$

Step 2 – Calculate the filling loss. Using the data from the problem statement and Equation 2-3, the filling loss is calculated as follows:

$$L_F = 0.00014 \times M_V \times P_V \times (D^2 \times h)$$

$$L_F = 0.00014 \frac{lb-mol}{psia ft^3} \times 130 \frac{lb}{lb-mol} \times 0.009 psia \times ([40 ft]^2 \times 8 ft)$$

$$L_F = 0.00014 \frac{lb-mol}{psia ft^3} \times 130 \frac{lb}{lb-mol} \times 0.009 psia \times (12800 ft^2) = \mathbf{2.10 lb}$$

Step 3 – Calculate total VOCs from degassing. The total VOCs emitted is the sum of the clingage and filling loss as calculated by Equation 2-1.

$$L_C = L_W + L_F$$

$$L_C = 1.58 lb + 2.10 lb = \mathbf{3.68 lb}$$

Step 4 – Calculate emitted HAPs from degassing. The problem stated that the total weight percent of HAPs in vapor is 25.2%. Using this value, the VOCs from degassing, and Equation 2-10, the total HAPs are calculated as follows:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

$$E_{HAP} = 3.68 lb \times \frac{25.2\%}{100\%}$$

$$E_{HAP} = 3.68 lb \times 0.252 = \mathbf{0.93 lb}$$

Step 5 – Calculate the volume of the remaining sludge. The problem stated that the tank was vertical and the sludge was approximately 6 inches thick. The volume of the sludge is estimated as follows:

$$V_S = \pi \times \frac{D^2}{4} \times t$$

$$V_S = \pi \times \frac{(40 ft)^2}{4} \times 6 in \times \frac{1 ft}{12 in}$$

$$V_S = \pi \times 400 ft^2 \times 0.5 ft = \mathbf{628.3 ft^3}$$

Step 6 – Calculate the weight of the sludge remaining in the tank. With the clingage and filling losses calculated, the emissions from the remaining sludge must be estimated. The next step is to calculate the weight. Since the specific gravity of the sludge is not known, it is assumed to be 1. With this information, the sludge volume calculated in Step 5, and Equation 2-5, the weight is calculated as follows:

$$W = S.G. \times 62.3 \times V_S$$

$$W = 1 \times 62.3 \frac{lb}{ft^3} \times 628.3 ft^3 = 39,143.1 lb$$

Step 7 – Estimate emissions from the evaporation of the VOC in the sludge. Again, since the sludge was not tested to determine the VOC content, a conservative estimate of 20% may be used. VOC emissions from the sludge are estimated using Equation 2-4 as shown:

$$E(Sludge)_{VOC} = W \times \frac{WP_{VOC}}{100}$$

$$E(Sludge)_{VOC} = 39,143.1 lb \times \frac{20\%}{100\%}$$

$$E(Sludge)_{VOC} = 39,143.1 lb \times 0.2 = 7828.6 lb$$

Step 8 – Calculate HAPs from the remaining sludge. Using the weight percent of HAPs in the liquid phase as given in the problem statement (1.1%), the VOCs calculated in Step 7, and Equation 2-10, the HAPs are calculated as follows:

$$E_{HAP} = E_{VOC} \times \frac{WP_{HAP}}{100}$$

$$E_{HAP} = 7828.6 lb \times \frac{1.1\%}{100\%}$$

$$E_{HAP} = 7828.6 lb \times 0.011 = 86.11 lb$$

Step 9 – Calculate total VOCs from storage tank cleaning. VOC emissions from degassing and sludge evaporation have been calculated and may be summed for total VOC. Note that emissions from the application of the degreasing solution do not contribute to VOC emissions since the components were stated to be inorganic HAPs. VOC emissions are calculated as follows:

$$E(Total)_{VOC} = \sum_{i=1}^n (E_{VOC_i} + \cdots + E_{VOC_n})$$

$$E(Total)_{VOC} = 1.58 lb + 2.10 lb + 7828.6 lb$$

$$\boxed{E(Total)_{VOC} = 7832.3 \text{ lb}}$$

Step 10 – Calculate HAPs from the applied solvent. It is assumed that the total solvent which is not recovered completely evaporates. The HAPs emitted from the application of solvent are calculated using the mass of solvent applied and recovered, the weight percent HAPs in the solvent (as provided in the problem statement), and Equation 2-6 as follows:

$$E_{Pol} = (M_A - M_R) \times \frac{WP_{Pol}}{100}$$

$$E_{HAP} = (120 \text{ lb} - 102 \text{ lb}) \times \frac{50\%}{100\%}$$

$$E_{HAP} = (18 \text{ lb}) \times 0.5 = \mathbf{9.0 \text{ lb}}$$

Step 11 – Calculate total HAPs. The total HAPs from the cleaning of storage tanks is the sum of the HAPs from degassing, remaining sludge, and solvent applied as shown:

$$E(Total)_{HAP} = \sum_{i=1}^n (E_{HAP_i} + \dots + E_{HAP_n})$$

$$E(Total)_{HAP} = 0.93 \text{ lb} + 86.11 \text{ lb} + 9.0 \text{ lb}$$

$$\boxed{E(Total)_{HAP} = 96.0 \text{ lb}}$$

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

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

USEPA 2006, 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

USEPA 2012, "TANKS Software Frequent Questions", U.S. Environmental Protection Agency, Technology Transfer Network Clearinghouse for Inventories & Emission Factors, <<http://www.epa.gov/ttnchie1/faq/tanksfaq.html#13>>, November 11, 2012

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3 BURN, OPEN AND PRESCRIBED (OPB)

➤ *Fugitive Source*

3.1 Introduction

“Burn” refers to the use of open and prescribed burning. These operations are used to dispose of agricultural refuse and the clearing and management of natural resources. **These operations result in the fugitive emissions of the 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, with the exception of ordnance, whose emissions calculations are described in the Stationary Guide.

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, is important in certain instances.

3.1.2 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 for the purpose of reducing the potential for wildfires, for removing logging residues, for controlling insects and disease, for increasing water yield or for 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 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, lead to varying amounts of emitted pollutants. A simple control volume for open and prescribed burns is provided in Figure 3-1.

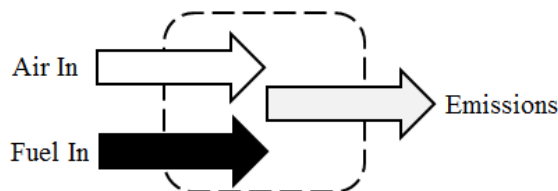


Figure 3-1. Simplified Open/Prescribed Burn Control Volume

3.2 NSPS Applicability

There are several New Source Performance Standards (NSPS) which have been set by the EPA which apply specifically to air curtain incinerators. For any base which 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 emission limits, testing requirements, and reporting and recording 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 which may apply. The following subparts to 40 CFR 60 have provisions specific to air curtain incinerators: Cb - Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that are Constructed on or Before September 20, 1994; 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; 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; BBBB – Emission Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999; CCCC – Standards of Performance for Commercial and Industrial Solid Waste Incineration Units; DDDD – Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units; 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; 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 an on-base air curtain, refer to the appropriate subpart.

3.3 Emission Factors

AP-42 provides several emission factors for open and prescribed burning in sections 2.5 and 13.1 respectively. Though these emission factors were developed through testing, it is preferable to use on-site data whenever available since those provided in AP-42 are statistical averages. When on-site testing is not available, the emission factors used for emissions calculation may be used.

3.3.1 Open Burning

Emission factors have been developed for open/prescribed 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 is typically negligible. For open burning, AP-42 provides emission factors for several types of agricultural materials in units of pounds per ton of refuse burned. Table 3-1 provides criteria pollutant emission factors and 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). For enhanced accuracy outside of on-site test data, refer to chapter 2.5 of AP-42 for species-specific emission factors.

Table 3-1. Criteria Pollutant Emission Factors for Open Burning of Agricultural Materials

Agricultural Material ¹	Fuel Loading Factor (ton/acre)	Emission Factors (lb/ton)							
		NO _x	CO	SO _x	Pb	VOC ²	PM ₁₀ ⁽³⁾	PM _{2.5} ⁽³⁾	GHG ⁴
Field Crops	2	---	117	---	---	18	20.66	19.70	2186.60
Leaf Burning	---	---	112	---	---	28	37.39	35.64	2186.60
Orchard Crops	1.6	---	52	---	---	8	5.89	5.55	2186.60
Vine Crops	2.5	---	51	---	---	5	4.92	4.69	2186.60
Weeds	3.2	---	85	---	---	9	14.76	14.07	2186.60
Forest Residues - Unspecified	70	4	140	---	---	19	16.34	14.52	3663.03
Forest Residues - Hemlock, Douglas Fir, Cedar	---	4	90	---	---	4	3.84	3.42	3663.03
Forest Residues - Ponderosa Pine	---	4	195	---	---	11	11.53	10.25	3663.03
Air Curtain Incinerators									
Wood	---	4	---	0.1	---	---	3.90	2.60	3663.03

SOURCE: 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

1. Unless otherwise specified, the agricultural material is "unspecified."
2. VOC emission factor provided is the non-methane TOC emission factor provided in source document.
3. Source document provides emission factors for PM. These values calculated using the PM₁₀ 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
4. Greenhouse gas emission factor is the sum of the product of CO₂, CH₄, N₂O and their respective global warming potentials (GWP). The global warming potentials are 1, 25, and 298 for CO₂, CH₄, and N₂O respectively. Emission factors taken from 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

"---" – Indicates No Data Available.

Air curtain incinerators, which are also known as trench combustors, 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 combustion is taking place. Emission factors have been developed for air curtain incinerators burning wood, tires, or municipal refuse. However, since air curtain incinerators are likely only to be used for open burning of agricultural materials, the only emission factors presented in Table 3-1 are those burning wood. For additional information, refer to section 2.1 of AP-42.

Table 3-2. Criteria Pollutant Emission Factors for Prescribed Burns

Fuel or Fire Configuration	Combustion Phase	Emission Factor (lb/ton)							
		NO _x	CO	SO _x	Pb	VOC ¹	PM ₁₀	PM _{2.5}	GHG ²
Broadcast Burn									
Chaparral	Flaming	---	119	---	---	17.2	16.5	13.5	3548.08
	Smoldering	---	197	---	---	30.6	24.7	21.6	3506.08
	Fire Average	---	154	---	---	19.6	20.1	17.3	3536.58
Conifer - Short Needle (e.g. Douglas Fir/Hemlock)	Flaming	---	143	---	---	4.2	16.6	14.9	3637.08
	Smoldering	---	463	---	---	8.4	27.6	26.1	3321.08
	Fire Average	---	312	---	---	7.2	23.1	21.8	3494.08
Conifer - Long Needle (e.g. Ponderosa Pine)	Flaming	---	89	---	---	3.6	11.5	10	3613.08
	Smoldering	---	285	---	---	9.6	36.7	34.2	3473.08
	Fire Average	---	178	---	---	6.4	25	22	3544.08
Conifer - Mixed	Flaming	---	53	---	---	3.2	11.7	9.6	3670.08
	Smoldering	---	273	---	---	13.2	25.3	23.6	3600.08
	Fire Average	---	201	---	---	9.8	20.5	18.8	3622.08
Hardwoods	Flaming	---	92	---	---	5.2	14	12.2	3636.08
	Smoldering	---	366	---	---	14	25.9	23.4	3478.08
	Fire Average	---	256	---	---	10.8	25	22.4	3539.08
Juniper	Flaming	---	82	---	---	5.5	15.3	13.9	3635.58
	Smoldering	---	250	---	---	15.5	25.8	23.8	3699.58
	Fire Average	---	163	---	---	10.4	20.4	18.7	3668.08
Sagebrush	Flaming	---	155	---	---	6.8	31.8	29.1	3519.08
	Smoldering	---	212	---	---	14.5	29.6	26.4	3565.08
	Fire Average	---	206	---	---	13.7	29.9	26.7	3560.58
Slash Pile Burn									
Dozer Piled Conifer - No Mineral Soil ³	Flaming	---	56	---	---	---	8	8	3621.58
	Smoldering	---	132	---	---	---	14	12	3621.58
	Fire Average	---	74	---	---	---	8	8	3621.58

SOURCE: "Smoke Management Guide for Prescribed and Wildland Fire: 2001 Edition," National Wildfire Coordinating Group (NWCG), Fire Use Working Team, December 2001

1. Emission factor given for VOC is the same as that provided in source document for non-methane hydrocarbons.
2. Emission factors are the sum of the product of the emission factors for CO₂, CH₄, and N₂O and their respective global warming potentials (GWP). The GWP for CO₂, CH₄, and N₂O are 1, 25, and 298 respectively. All N₂O emission factors from AP-42. The remaining emission factors from "Smoke Management Guide for Prescribed and Wildland Fire: 2001 Edition," National Wildfire Coordinating Group (NWCG), Fire Use Working Team, December 2001
3. 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

"---" – Indicates No Data Available

Note that AP-42 provides emission factors for generalized areas of the United States that estimates a percentage for each vegetation type. Refer to AP-42 for these emission factors for more information.

3.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. For both open and prescribed burning, the emission factors provided above are sufficient for the general calculation of emissions. However, for enhanced accuracy, refer to section 2.5 or 13.1 for more information regarding species or region-specific emission factors for open and prescribed burns.

Calculation of emissions from either open or prescribed burns is accomplished by taking the product of the total mass burned and the respective emission factor as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

Equation 3-1

Where,

- E_{Pol}** = Annual emission of pollutant (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 estimation. For convenience, average fuel loading factors are provided in Table 3-1 and may be used to estimate the mass burned as follows:

$$Q = A \times LF$$

Equation 3-2

Where,

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

The emissions from open and prescribed burning are graphically represented in Figure 3-2.

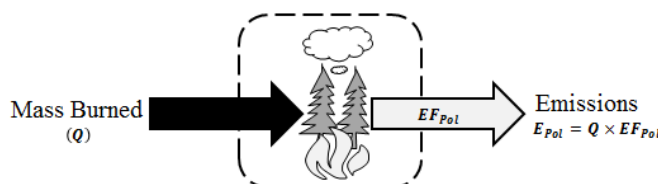


Figure 3-2. Open/Prescribed Burn Control Volume

3.5 Information Resources

The base Civil Engineering organization is typically responsible for conducting open and prescribed burns on base. Therefore, Base Civil Engineering should be contacted to provide estimates on the type and quantities of vegetation burned. If prescribed burning is performed, it may be appropriate to contact a government agency, such as the U.S. Forest Service or State/local forestry agency, for additional information. These agencies may be able to provide guidance in determining fuel loading factors and/or vegetation types for each region of the country.

3.6 Example Problems

3.6.1 Problem #1 (Open Burn)

Last year, Anytown AFB cleared 6.5 acres of land on base. The agricultural material on this land was primarily weeds which were disposed through open burning. Calculate the CO, VOC, PM₁₀, PM_{2.5}, and Greenhouse gas 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 3-1, 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:

$$Q = A \times LF$$

$$Q = 6.5 \frac{\text{Acres}}{\text{yr}} \times 3.2 \frac{\text{ton}}{\text{acre}} = 20.8 \frac{\text{ton}}{\text{yr}}$$

Step 3 – Record emission factors. According to Table 3-1, the emission factors for CO, VOC, PM₁₀, PM_{2.5}, and GHG are **85, 9, 14.76, 14.07, and 2186.60 lb/ton** respectively.

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

$$E_{Pol} = Q \times EF_{Pol}$$

$$E_{CO} = 20.8 \frac{\text{ton}}{\text{yr}} \times 85 \frac{\text{lb}}{\text{ton}}$$

$$E_{CO} = 1,768 \frac{\text{lb}}{\text{yr}}$$

$$E_{VOC} = 20.8 \frac{\text{ton}}{\text{yr}} \times 9 \frac{\text{lb}}{\text{ton}}$$

$$E_{VOC} = 187.2 \frac{\text{lb}}{\text{yr}}$$

$$E_{PM_{10}} = 20.8 \frac{\text{ton}}{\text{yr}} \times 14.76 \frac{\text{lb}}{\text{ton}}$$

$$E_{PM_{10}} = 307 \frac{\text{lb}}{\text{yr}}$$

$$E_{PM_{2.5}} = 20.8 \frac{\text{ton}}{\text{yr}} \times 14.07 \frac{\text{lb}}{\text{ton}}$$

$$E_{PM_{2.5}} = 292.7 \frac{\text{lb}}{\text{yr}}$$

$$E_{GHG} = 20.8 \frac{\text{ton}}{\text{yr}} \times 2186.60 \frac{\text{lb}}{\text{ton}}$$

$$E_{GHG} = 45,481.3 \frac{\text{lb}}{\text{yr}}$$

3.6.2 Problem #2 (Prescribed Burn)

Last year, Anytown AFB performed prescribed burning in an area on base. Base Civil Engineering estimates that a total of 19 tons of slash was broadcast burned. After contacting the U.S. Forest Service, it is determined that for this part of the country, the fuel composition was 25% chaparral, 25% mixed conifer, 20% long needle conifer, 15% sagebrush, and 15% Douglas Fir. Calculate the total PM_{2.5} emissions from this operation.

Step 1 – Select and record emission factors. The type of burn (flaming versus smoldering) was not provided for this operation. Therefore, the fire average may be used. According to Table 3-2, the emission factors for PM_{2.5} for chaparral, mixed conifer, long needle conifer, sagebrush, and Douglas Fir are: **17.3, 18.8, 22, 26.7, and 21.8 lb/ton**, respectively.

Step 2 – Calculate emissions for each vegetation type. This is done using the total mass burned as given in the problem statement, the emission factors recorded in Step 1, and Equation 3-1. Note that the mass burned is the product of the total burned and the percent of each type of vegetation burned as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

$$E(\textit{Chaparral})_{PM_{2.5}} = 19 \frac{\cancel{\text{ton}}}{\text{yr}} \times \frac{25\%}{100\%} \times 17.3 \frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{82.2 \frac{lb}{yr}}$$

$$E(\textit{Mixed Conifer})_{PM_{2.5}} = 19 \frac{\cancel{\text{ton}}}{\text{yr}} \times \frac{25\%}{100\%} \times 18.8 \frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{89.3 \frac{lb}{yr}}$$

$$E(\textit{Long Needle Conifer})_{PM_{2.5}} = 19 \frac{\cancel{\text{ton}}}{\text{yr}} \times \frac{20\%}{100\%} \times 22 \frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{83.6 \frac{lb}{yr}}$$

$$E(\textit{Sagebrush})_{PM_{2.5}} = 19 \frac{\cancel{\text{ton}}}{\text{yr}} \times \frac{15\%}{100\%} \times 26.7 \frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{76.1 \frac{lb}{yr}}$$

$$E(\textit{Douglas Fir})_{PM_{2.5}} = 19 \frac{\cancel{\text{ton}}}{\text{yr}} \times \frac{15\%}{100\%} \times 21.8 \frac{\text{lb}}{\cancel{\text{ton}}} = \mathbf{62.1 \frac{lb}{yr}}$$

Step 3 – Calculate total emissions. Total $PM_{2.5}$ emissions are the sum of the emissions calculated in Step 2 as follows:

$$E(\textit{Total})_{Pol} = \sum_{i=1}^n (E_{Pol_i} + \cdots + E_{Pol_n})$$

$$E(\textit{Total})_{PM_{2.5}} = (82.2 + 89.3 + 83.6 + 76.1 + 62.1) \frac{\text{lb}}{\text{yr}}$$

$$\boxed{E(\textit{Total})_{PM_{2.5}} = \mathbf{393.3 \frac{lb}{yr}}}$$

3.7 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 September 20, 1994 or for Which Modification or Reconstruction 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 or for Which Modification or Reconstruction is Commenced After June 6, 2001," 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-Emission 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 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

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NWCG 2001, "Smoke Management Guide for Prescribed and Wildland Fire: 2001 Edition," National Wildfire Coordinating Group (NWCG), Fire Use Working Team, December 2001

Robinson 2011, Robinson, Marin S., et al, "Characterization of PM_{2.5} Collected During Broadcast and Slash-Pile Prescribed Burns of Predominantly Ponderosa Pine Forests in Northern Arizona," April 2011

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

USEPA 1996, 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

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 even 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 result from exhaust from motorized vehicles/equipment whose emissions calculations are described in the Mobile Guide.

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 area and volume of the construction activity and average commuting distance for the workers. Programs such as the Air Conformity and 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. Default values for use in emissions calculations may be taken from URBEMIS (Urban Emissions software), an emissions estimation computer program developed for estimating emissions associated with land development projects.

4.1.1 Construction Phases

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

- 1) Demolition
- 2) Site Grading
- 3) Trenching/Excavation
- 4) Building Construction
- 5) Architectural Coating
- 6) Asphalt Paving

Each construction phase results in a unique combination of construction emission classes. There are five 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/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), Exhaust (On-road vehicles), and Worker Trips in calculating the overall emissions associated with site grading.

Demolition involves the tearing down of buildings or other obstacles and removing the remaining debris off site. Buildings may be demolished using loaders, bulldozers, or demolition excavators or buildings may be torn through the use of carefully placed explosives which result in building implosions.

Site grading 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 also to improve drainage around new or existing facilities.

Excavating and trenching involves the digging and removing of soil and rock. This may be done for the purpose of laying pipe or cable or for drainage purposes. Excavated soil may be kept on site for the purpose of filling or backfilling open cavities and for use in site grading. Any excess excavated material not used on site is moved to an offsite location to be used elsewhere.

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 increase. 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 for 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 emission factors for the calculation of actual emissions. This is due to the decline in cutback asphalt use in favor of emulsified asphalt. **The emission factor for VOCs from emulsified asphalt and asphalt cement are essentially assumed to be zero.**

4.2 Emission Standards

The EPA has established air emission standards for nonroad engines in an effort to gradually decrease air emissions. 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

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. 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:

$$E_{Pol} = \sum_{i=1}^n E_{Pol_i}$$

Equation 4-1

Where,

- E_{Pol}** = Emissions of individual pollutant for entire construction project (lb)
E_{Poli} = Emissions of individual pollutant for an individual construction phase (lb)
i = Denotes the individual construction phase (i.e., Demolition, Site Grading, Trenching, Building Constriction, Architectural Coatings, or Paving)

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

$$E_{Pol_i} = E(\text{Fugitive Dust})_{Pol} + E(\text{Construction Exhaust})_{Pol} \\ + E(\text{Vehicle Exhaust})_{Pol} + E(\text{Worker Trips})_{Pol} + E(\text{Vendor Trips})_{Pol} \\ + E(\text{Off - Gassing})_{Pol}$$

Equation 4-2

4.3.1 Fugitive Dust

Significant atmospheric dust arises from the mechanical disturbance of granular material exposed to the air during construction **Demolition, Site Grading, and Trenching** operations. Dust generated from these open 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 emission factor to the area and height as shown:

$$E_{PM_{10}} = 0.00042 \times BA \times BH$$

Equation 4-3

Where,

- E_{PM10}** = PM_{10} emissions (lb)
0.00042 = Emission factor (lb/ft³)
BA = Area of building to be demolished (ft²)
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's) California Environmental Quality Act (CEQA) Air Quality Handbook (SCAQMD 2007).

4.3.1.2 Site Grading, Excavation and Trenching Fugitive Dust Emissions

The fugitive dust emission 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 general rule, the grading area should be about twice the size of the building being demolished.**
WD = Work duration, estimated in work days (Days). **Note that this is work days, 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, cranes, graders, bulldozers, etc. Emissions from off-road equipment are estimated using the total operating time of the equipment and the appropriate emission factor. The operating time is estimated using the per day average use in hours of each equipment type. In the absence of on-site data, typical operating times for different types of equipment may be either estimated or taken from URBEMIS. Emissions from each off-road engine may be calculated using the emission factors, based on construction year, provided in Table 4-2 through Table 4-13. Emissions are calculated as follows:

$$E_{Pol} = \sum_{i=1}^n (WD \times H \times N_i \times EF_{Pol_i})$$

Equation 4-5

Where,

- WD** = Work duration (days)
E_{Pol} = Emissions of individual pollutant for all equipment types (lb)
H = Hours worked per day (hr/day)
N_i = Number of specific pieces of equipment
EF_{Pol_i} = Emission factor for specific equipment (lb/hr)
i = Denotes the individual equipment types

4.3.3 Vehicle Exhaust (On-Road) Emissions

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

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
Building Construction	Hauling construction materials to the site
Architectural Coatings	N/A
Paving	Hauling asphalt to the site

The calculation of on-road vehicle exhaust emissions is the same for all construction phases. Emissions for each pollutant are estimated by multiplying the vehicle miles travelled (VMT) by the Emission Factor for Heavy-Duty Diesel Vehicles (HDDV), which may be found in the appropriate section of the Mobile Guide:

$$E_{Pol} = VMT \times 0.002205 \times \sum_{i=1}^n \left(EF_{Pol_i} \times \frac{VM_i}{100} \right)$$

Equation 4-6

Where,

- VMT** = Vehicle miles travelled (miles)
0.002205 = Factor for converting g to lb (lb/g)
EF_{Pol_i} = Specific pollutant emission factor provided in the Mobile Guide (g/mile)
VM_i = Vehicle Mix (%). **For vehicle exhaust, VM_i is 100% HDDV.**
100 = Factor converting percent to a fraction (%)
i = Denotes vehicle category – i.e., LDGV, LDGT, HDDV, 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:

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

Equation 4-7

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:

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

Equation 4-8

Where,

BA = Area of building to be demolished (ft²)

BH = Height of building to be demolished (ft)

27 = Factor converting ft³ to yd³ (yd³/ft³)

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

HC = Average truck hauling capacity per trip (yd³/trip). **Assume 20 yd³/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:

$$\text{Round Trips}_{\text{Fill}} = \text{FILL} \times \frac{1}{HC}$$

Equation 4-9

$$\text{Round Trips}_{\text{Cut}} = \text{CUT} \times \frac{1}{\text{HC}}$$

Equation 4-10

Where,

FILL = Amount of fill material hauled to the site (ft³)**CUT** = Amount of cut material hauled away from the site (ft³)**HC** = Average truck hauling capacity per trip (yd³/trip). Assume 20 yd³/trip if unknown.

4.3.3.3 Building Construction Material Round Trips

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

Military Family Housing:

$$\text{Round Trips}_{\text{Multifamily}} = N \times 0.36$$

Equation 4-11

$$\text{Round Trips}_{\text{Single-Family}} = N \times 0.72$$

Equation 4-12

Base Exchange, Commissary, etc.:

$$\text{Round Trips}_{\text{Commercial or Retail}} = \text{CA} \times \frac{1}{1000} \times 0.32$$

Equation 4-13

Offices or Industrial Buildings:

$$\text{Round Trips}_{\text{Office or Industrial}} = \text{CA} \times \frac{1}{1000} \times 0.42$$

Equation 4-14

Where,

N = Number of units**0.36/0.72** = Factor converting units to trips (trips/unit)**CA** = Construction area (ft²)**1000** = Factor converting ft² to 10³ ft² (10³ ft²/ft²)**0.32/0.42** = Factor converting 10³ ft² to trips (trips/10³ ft²)

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:

$$\text{Round Trips}_{\text{Paving}} = PA \times 0.25 \times \frac{1}{27} \times \frac{1}{HC}$$

Equation 4-15

Where,

- PA** = Paving area (ft²)
- 0.25** = Thickness of paved area (ft)
- 27** = Factor converting ft³ to yd³
- HC** = Average truck hauling capacity per trip (yd³/trip). Assume 20 yd³/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 worker commuting may be estimated using Equation 4-6 but **assumes a vehicle mix (VM_i) of 50% LDGV and 50% LDGT**. The method for estimating VMT from worker commuting is different than the method provided above for estimating VMT from vehicle exhaust. The VMT estimating methods for each construction phase are provided below.

4.3.4.1 VMT Estimates for all 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 worker 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 work days, an estimate of VMT is possible:

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

Equation 4-16

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 ft²/day, would need to commute to complete painting the area to be coated:

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

Equation 4-17

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 (ft²)
- 800** = Assumed worker rate of paint application (ft²/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 4-7 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:

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

Equation 4-18

Base Exchange, Commissary, etc.:

$$\text{Round Trips}_{\text{Commercial or Retail}} = CA \times \frac{1}{1000} \times 0.05$$

Equation 4-19

Offices or Industrial Buildings:

$$\text{Round Trips}_{\text{Office or Industrial}} = CA \times \frac{1}{1000} \times 0.38$$

Equation 4-20

Where,

- N** = Number of units
CA = Construction area (ft²)
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 nonresidential architectural coatings. Emissions are based on the total surface area to be coated (ft²), the coating coverage (ft²/gal), and VOC content (g/L) of the coating.

Surface Areas Size

The interior and exterior square feet to be painted (SA) is estimated using the following equations:

Military Family Housing (MFH):

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

Equation 4-21

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

Equation 4-22

Where,

- N** = Number of units

- 850** = Factor converting units to square feet (ft²/units)
1800 = Factor converting units to square feet (ft²/units)
2.7 = Factor converting total area to coated area

All Other Buildings:

$$SA_{Non-Residential} = BA \times 2$$

Equation 4-23

Where,

- BA** = Total building square footage (ft²)
2 = Factor converting building square footage to surface area

Emission Factor:

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

$$EF_{voc} = \frac{250 \text{ g VOCs}}{1 \text{ L Paint}} \times \frac{1 \text{ gal Paint}}{180 \text{ ft}^2} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{3.785 \text{ L}}{1 \text{ gal}} = 0.0116 \frac{\text{lb}}{\text{ft}^2}$$

Emissions Estimate:

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

$$E_{voc} = SA \times 0.0116$$

4.3.6.2 Paving (Asphalt)

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

$$E_{voc} = \frac{PA \times 2.62}{43,560}$$

Equation 4-24

Where,

- PA** = Paving area (ft²)
2.62 = Emission factor (lb/acre)
43,560 = Factor converting square feet to acres (ft²/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 and URBEMIS. Refer to the supporting documentation for these programs for assumptions made and guidance in estimating emissions.

4.5 Example Problem

During CY2014, Anytown AFB (located in Alabama – 600 feet above sea level) contracted a company to demolish an existing building. The building was described as 5000 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 120hp tractors, one 250hp rubber tired dozer, and one 50hp concrete saw were used. The contractor's best estimate was that the tractors, dozer, and saw operated for 6, 1, and 8 hours per day on average. Calculate the PM₁₀ emissions from the demolition of this building.

Step 1 – 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.**

Step 2 – Calculate fugitive dust emissions. Using the building area, height, and Equation 4-3, PM₁₀ emissions are calculated as shown:

$$E_{PM_{10}} = 0.00042 \times BA \times BH$$

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

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

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

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

Step 4 – Select and record the appropriate emission factors. Construction equipment emission factors for 2014 are provided in Table 4-2. The emission factors for the tractor, dozer, and saw are **0.034, 0.099, and 0.041 lb/hr, respectively.**

Step 5 – Calculate Construction exhaust emissions. Using the emission factors provided in Step 4, the work days estimated in Step 3, the data in the problem statement, and Equation 4-5, the emissions from construction exhaust are calculated as follows:

$$E_{Pol} = \sum_{i=1}^n (WD \times H \times N_i \times EF_{Pol_i})$$

$E(\text{Construction Exhaust})_{PM_{10}}$

$$= \left[\left(20 \text{ days} \times 6 \frac{\text{hr}}{\text{day}} \times 2 \times 0.034 \frac{\text{lb}}{\text{hr}} \right) + \left(20 \text{ days} \times 1 \frac{\text{hr}}{\text{day}} \times 1 \times 0.099 \frac{\text{lb}}{\text{hr}} \right) + \left(20 \text{ days} \times 8 \frac{\text{hr}}{\text{day}} \times 1 \times 0.041 \frac{\text{lb}}{\text{hr}} \right) \right]$$

$$E(\text{Construction Exhaust})_{PM_{10}} = [(8.16 \text{ lb}) + (1.98 \text{ lb}) + (6.56 \text{ lb})] = \mathbf{16.7 \text{ lb}}$$

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 which 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 yd³/trip, an estimate of the number of round trips may be calculated using Equation 4-8:

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

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

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

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

$$\text{Round Trips} = 166.67 \text{ trip} \times 0.25 = \mathbf{41.67 \text{ trips}}$$

Step 7 – 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 4-7:

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

$$\text{VMT} = 41.67 \text{ trips} \times 20 \frac{\text{miles}}{\text{trip}} = \mathbf{833.33 \text{ miles}}$$

Step 8 – Select and record the appropriate emission factor. The vehicle mix for vehicle exhaust emissions is assumed to be 100% HDDV. For PM₁₀, the Mobile Guide states the emission factor is **0.065 g/mile**.

Step 9 – Calculate vehicle exhaust emissions. Using the emission factor recorded in Step 8, the VMT calculated in Step 7, and Equation 4-6, the PM₁₀ emissions from vehicle exhaust is calculated as follows:

$$E_{Pol} = VMT \times 0.002205 \times \sum_{i=1}^n \left(EF_{Pol_i} \times \frac{VM_i}{100} \right)$$

$$E(\text{Vehicle Exhaust})_{PM_{10}} = 833.33 \text{ miles} \times 0.002205 \frac{lb}{g} \times 0.065 \frac{g}{mile} \times \frac{100\%}{100\%}$$

$$E(\text{Vehicle Exhaust})_{PM_{10}} = 833.33 \text{ miles} \times 0.002205 \frac{lb}{g} \times 0.065 \frac{g}{mile} \times 1 = \mathbf{0.119 lb}$$

Step 10 – Estimate the VMT for worker commuting. Assuming an average worker commute of 20 miles/trip, the work days estimated in Step 3, and Equation 4-16, the VMT is calculated as follows:

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

$$VMT = 1 \frac{trip}{day} \times 20 \text{ days} \times 20 \frac{miles}{trip} \times 1.25 \times 4 = \mathbf{2000 \text{ miles}}$$

Step 11 – Select and record the appropriate emission factors. Assuming a mix of LDGV and LDGT for worker vehicle types, the emission factors for PM₁₀ from the Mobile Guide are **0.025 and 0.025 g/miles** respectively.

Step 12 – Calculate emissions from worker trips. Using Equation 4-6, the VMT calculated in Step 10, the emission factors recorded in Step 11, and an assumed vehicle mix of 50% LDGV and 50% LDGT, the PM₁₀ emissions are calculated as follows:

$$E_{Pol} = VMT \times 0.002205 \times \sum_{i=1}^n \left(EF_{Pol_i} \times \frac{VM_i}{100} \right)$$

$$E(\text{Worker Trips})_{PM_{10}} = 2000 \text{ miles} \times 0.002205 \frac{lb}{g} \times \left[\left(0.025 \frac{g}{mile} \times \frac{50\%}{100\%} \right) + \left(0.025 \frac{g}{mile} \times \frac{50\%}{100\%} \right) \right]$$

$$E(\text{Worker Trips})_{PM_{10}} = 2000 \text{ miles} \times 0.002205 \frac{\text{lb}}{\text{g}} \times \left[\left(0.025 \frac{\text{g}}{\text{mile}} \times 0.5 \right) + \left(0.025 \frac{\text{g}}{\text{mile}} \times 0.5 \right) \right]$$

$$E(\text{Worker Trips})_{PM_{10}} = 2000 \text{ miles} \times 0.002205 \frac{\text{lb}}{\text{g}} \times \left[\left(0.0125 \frac{\text{g}}{\text{mile}} \right) + \left(0.0125 \frac{\text{g}}{\text{mile}} \right) \right]$$

$$E(\text{Worker Trips})_{PM_{10}} = 2000 \text{ miles} \times 0.002205 \frac{\text{lb}}{\text{g}} \times \left[0.025 \frac{\text{g}}{\text{mile}} \right] = \mathbf{0.11 \text{ lb}}$$

Step 13 – Calculate total PM₁₀. The final step is to sum the PM₁₀ emissions from each class comprising the demolition phase of construction using Equation 4-2:

$$E_{Pol_i} = E(\text{Fugitive Dust})_{Pol} + E(\text{Construction Exhaust})_{Pol} + E(\text{Vehicle Exhaust})_{Pol} + E(\text{Worker Trips})_{Pol} + E(\text{Vendor Trips})_{Pol} + E(\text{Off – Gassing})_{Pol}$$

$$E_{PM_{10}Demolition} = 37.8 \text{ lb} + 16.7 \text{ lb} + 0.119 \text{ lb} + 0.11 \text{ lb} + 0 + 0$$

$E_{PM_{10}Demolition} = \mathbf{54.73 \text{ lb}}$

Table 4-2. Criteria Pollutant Emission Factors for Off-Road Equipment - 2014

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.287	0.188	0.000	0.048	0.018	0.018	34.831
Air Compressors	0.563	0.331	0.001	0.084	0.040	0.040	63.797
Bore/Drill Rigs	0.714	0.503	0.002	0.073	0.025	0.025	165.103
Cement and Mortar Mixers	0.055	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.527	0.403	0.001	0.092	0.041	0.041	58.671
Cranes	1.107	0.455	0.001	0.128	0.047	0.047	128.923
Crawler Tractors	1.085	0.577	0.001	0.150	0.064	0.064	114.358
Crushing/Proc. Equipment	1.087	0.665	0.001	0.160	0.068	0.068	132.670
Dumpers/Tenders	0.059	0.032	0.000	0.009	0.003	0.003	7.646
Excavators	0.830	0.529	0.001	0.114	0.043	0.043	119.838
Forklifts	0.355	0.221	0.001	0.050	0.018	0.018	54.508
Generator Sets	0.508	0.297	0.001	0.070	0.030	0.030	61.151
Graders	1.080	0.599	0.001	0.136	0.054	0.054	133.050
Off-Highway Tractors	1.611	0.744	0.002	0.199	0.077	0.077	151.877
Off-Highway Trucks	1.668	0.615	0.003	0.203	0.058	0.058	260.522
Other Construction Equipment	0.717	0.370	0.001	0.082	0.030	0.030	122.816
Other General Industrial Equipment	1.236	0.499	0.002	0.145	0.053	0.053	152.567
Other Material Handling Equipment	1.207	0.481	0.002	0.138	0.051	0.051	141.506
Pavers	0.811	0.528	0.001	0.143	0.056	0.056	78.256
Paving Equipment	0.731	0.427	0.001	0.108	0.050	0.050	69.186
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.084	0.060	0.000	0.015	0.005	0.005	9.446
Pumps	0.443	0.287	0.001	0.068	0.029	0.029	49.761
Rollers	0.616	0.402	0.001	0.091	0.042	0.042	67.258
Rough Terrain Forklifts	0.610	0.461	0.001	0.093	0.048	0.048	70.490
Rubber Tired Dozers	2.387	1.106	0.002	0.285	0.099	0.099	239.738
Rubber Tired Loaders	0.862	0.468	0.001	0.112	0.046	0.046	108.865
Scrapers	2.237	0.989	0.003	0.265	0.093	0.093	263.090
Signal Boards	0.133	0.093	0.000	0.018	0.007	0.007	16.739
Skid Steer Loaders	0.237	0.226	0.000	0.041	0.015	0.015	30.368
Surfacing Equipment	1.169	0.493	0.002	0.119	0.043	0.043	166.248
Sweepers/Scrubbers	0.635	0.509	0.001	0.103	0.045	0.045	78.775
Tractors/Loaders/Backhoes	0.498	0.375	0.001	0.073	0.034	0.034	66.965
Trenchers	0.638	0.461	0.001	0.135	0.052	0.052	59.021
Welders	0.244	0.204	0.000	0.059	0.021	0.021	25.735

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-3. Criteria Pollutant Emission Factors for Off-Road Equipment – 2015

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.267	0.184	0.000	0.044	0.017	0.017	34.821
Air Compressors	0.518	0.326	0.001	0.077	0.036	0.036	63.782
Bore/Drill Rigs	0.614	0.502	0.002	0.067	0.020	0.020	165.073
Cement and Mortar Mixers	0.055	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.492	0.398	0.001	0.084	0.037	0.037	58.652
Cranes	1.020	0.440	0.001	0.120	0.043	0.043	128.902
Crawler Tractors	1.006	0.565	0.001	0.141	0.059	0.059	114.338
Crushing/Proc. Equipment	0.989	0.655	0.001	0.146	0.061	0.061	132.640
Dumpers/Tenders	0.059	0.032	0.000	0.009	0.003	0.003	7.645
Excavators	0.742	0.525	0.001	0.106	0.038	0.038	119.820
Forklifts	0.316	0.220	0.001	0.046	0.016	0.016	54.499
Generator Sets	0.472	0.291	0.001	0.064	0.027	0.027	61.137
Graders	0.979	0.593	0.001	0.128	0.049	0.049	133.031
Off-Highway Tractors	1.508	0.724	0.002	0.189	0.072	0.072	151.851
Off-Highway Trucks	1.493	0.597	0.003	0.192	0.052	0.052	260.490
Other Construction Equipment	0.639	0.365	0.001	0.077	0.026	0.026	122.771
Other General Industrial Equipment	1.121	0.484	0.002	0.136	0.048	0.048	152.546
Other Material Handling Equipment	1.097	0.470	0.002	0.129	0.046	0.046	141.485
Pavers	0.761	0.520	0.001	0.135	0.053	0.053	78.238
Paving Equipment	0.684	0.423	0.001	0.102	0.047	0.047	69.172
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.080	0.059	0.000	0.013	0.005	0.005	9.444
Pumps	0.412	0.282	0.001	0.062	0.027	0.027	49.747
Rollers	0.571	0.398	0.001	0.085	0.039	0.039	67.242
Rough Terrain Forklifts	0.559	0.458	0.001	0.085	0.042	0.042	70.473
Rubber Tired Dozers	2.234	1.042	0.002	0.272	0.092	0.092	239.706
Rubber Tired Loaders	0.784	0.461	0.001	0.105	0.042	0.042	108.848
Scrapers	2.065	0.944	0.003	0.251	0.085	0.085	263.058
Signal Boards	0.125	0.093	0.000	0.017	0.007	0.007	16.737
Skid Steer Loaders	0.220	0.222	0.000	0.035	0.013	0.013	30.356
Surfacing Equipment	1.068	0.470	0.002	0.112	0.039	0.039	166.227
Sweepers/Scrubbers	0.575	0.503	0.001	0.091	0.039	0.039	78.749
Tractors/Loaders/Backhoes	0.450	0.372	0.001	0.067	0.030	0.030	66.949
Trenchers	0.604	0.454	0.001	0.127	0.048	0.048	59.003
Welders	0.230	0.199	0.000	0.053	0.019	0.019	25.723

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-4. Criteria Pollutant Emission Factors for Off-Road Equipment - 2016

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.248	0.180	0.000	0.040	0.015	0.015	34.811
Air Compressors	0.473	0.321	0.001	0.070	0.032	0.032	63.766
Bore/Drill Rigs	0.534	0.502	0.002	0.062	0.016	0.016	165.050
Cement and Mortar Mixers	0.054	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.459	0.394	0.001	0.076	0.034	0.034	58.634
Cranes	0.939	0.426	0.001	0.114	0.039	0.039	128.886
Crawler Tractors	0.931	0.555	0.001	0.133	0.055	0.055	114.320
Crushing/Proc. Equipment	0.897	0.646	0.001	0.134	0.054	0.054	132.611
Dumpers/Tenders	0.059	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.660	0.521	0.001	0.099	0.033	0.033	119.803
Forklifts	0.282	0.219	0.001	0.043	0.014	0.014	54.492
Generator Sets	0.437	0.286	0.001	0.058	0.024	0.024	61.124
Graders	0.887	0.588	0.001	0.120	0.044	0.044	133.013
Off-Highway Tractors	1.411	0.707	0.002	0.180	0.067	0.067	151.826
Off-Highway Trucks	1.332	0.583	0.003	0.182	0.046	0.046	260.461
Other Construction Equipment	0.568	0.360	0.001	0.072	0.023	0.023	122.725
Other General Industrial Equipment	1.012	0.473	0.002	0.127	0.043	0.043	152.526
Other Material Handling Equipment	0.991	0.461	0.002	0.120	0.041	0.041	141.465
Pavers	0.713	0.513	0.001	0.127	0.049	0.049	78.220
Paving Equipment	0.639	0.420	0.001	0.096	0.044	0.044	69.159
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.076	0.058	0.000	0.012	0.004	0.004	9.441
Pumps	0.383	0.278	0.001	0.056	0.024	0.024	49.733
Rollers	0.527	0.394	0.001	0.079	0.035	0.035	67.227
Rough Terrain Forklifts	0.510	0.455	0.001	0.078	0.037	0.037	70.456
Rubber Tired Dozers	2.089	0.983	0.002	0.259	0.086	0.086	239.675
Rubber Tired Loaders	0.711	0.456	0.001	0.098	0.037	0.037	108.833
Scrapers	1.902	0.905	0.003	0.238	0.078	0.078	263.027
Signal Boards	0.117	0.092	0.000	0.016	0.006	0.006	16.734
Skid Steer Loaders	0.204	0.218	0.000	0.030	0.011	0.011	30.346
Surfacing Equipment	0.973	0.451	0.002	0.104	0.035	0.035	166.208
Sweepers/Scrubbers	0.519	0.499	0.001	0.081	0.033	0.033	78.726
Tractors/Loaders/Backhoes	0.407	0.369	0.001	0.061	0.026	0.026	66.936
Trenchers	0.572	0.448	0.001	0.120	0.045	0.045	58.985
Welders	0.217	0.195	0.000	0.048	0.017	0.017	25.711

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-5. Criteria Pollutant Emission Factors for Off-Road Equipment - 2017

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.231	0.177	0.000	0.036	0.013	0.013	34.802
Air Compressors	0.432	0.317	0.001	0.064	0.028	0.028	63.752
Bore/Drill Rigs	0.469	0.501	0.002	0.058	0.013	0.013	165.025
Cement and Mortar Mixers	0.054	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.427	0.389	0.001	0.068	0.030	0.030	58.617
Cranes	0.862	0.415	0.001	0.107	0.035	0.035	128.870
Crawler Tractors	0.862	0.546	0.001	0.126	0.050	0.050	114.302
Crushing/Proc. Equipment	0.811	0.639	0.001	0.122	0.047	0.047	132.584
Dumpers/Tenders	0.059	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.586	0.518	0.001	0.092	0.029	0.029	119.786
Forklifts	0.249	0.218	0.001	0.040	0.012	0.012	54.486
Generator Sets	0.405	0.282	0.001	0.053	0.022	0.022	61.112
Graders	0.801	0.584	0.001	0.112	0.040	0.040	132.996
Off-Highway Tractors	1.318	0.691	0.002	0.172	0.062	0.062	151.802
Off-Highway Trucks	1.185	0.572	0.003	0.171	0.041	0.041	260.443
Other Construction Equipment	0.504	0.357	0.001	0.067	0.021	0.021	122.693
Other General Industrial Equipment	0.914	0.465	0.002	0.119	0.038	0.038	152.508
Other Material Handling Equipment	0.895	0.454	0.002	0.112	0.037	0.037	141.447
Pavers	0.667	0.507	0.001	0.119	0.045	0.045	78.203
Paving Equipment	0.597	0.417	0.001	0.091	0.040	0.040	69.146
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.073	0.057	0.000	0.011	0.004	0.004	9.439
Pumps	0.356	0.275	0.001	0.051	0.021	0.021	49.721
Rollers	0.487	0.391	0.001	0.074	0.032	0.032	67.212
Rough Terrain Forklifts	0.465	0.452	0.001	0.070	0.032	0.032	70.440
Rubber Tired Dozers	1.951	0.930	0.002	0.246	0.080	0.080	239.645
Rubber Tired Loaders	0.645	0.451	0.001	0.092	0.034	0.034	108.819
Scrapers	1.748	0.871	0.003	0.226	0.072	0.072	262.998
Signal Boards	0.110	0.092	0.000	0.015	0.005	0.005	16.732
Skid Steer Loaders	0.191	0.216	0.000	0.027	0.009	0.009	30.339
Surfacing Equipment	0.885	0.433	0.002	0.098	0.032	0.032	166.190
Sweepers/Scrubbers	0.473	0.496	0.001	0.074	0.029	0.029	78.710
Tractors/Loaders/Backhoes	0.368	0.367	0.001	0.056	0.022	0.022	66.923
Trenchers	0.541	0.442	0.001	0.113	0.042	0.042	58.969
Welders	0.205	0.191	0.000	0.043	0.015	0.015	25.701

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-6. Criteria Pollutant Emission Factors for Off-Road Equipment - 2018

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.215	0.174	0.000	0.032	0.012	0.012	34.794
Air Compressors	0.394	0.313	0.001	0.058	0.025	0.025	63.739
Bore/Drill Rigs	0.417	0.501	0.002	0.054	0.010	0.010	165.005
Cement and Mortar Mixers	0.054	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.396	0.385	0.001	0.060	0.026	0.026	58.600
Cranes	0.791	0.406	0.001	0.101	0.032	0.032	128.856
Crawler Tractors	0.796	0.539	0.001	0.118	0.046	0.046	114.285
Crushing/Proc. Equipment	0.733	0.633	0.001	0.111	0.041	0.041	132.559
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.518	0.516	0.001	0.085	0.025	0.025	119.771
Forklifts	0.219	0.217	0.001	0.037	0.010	0.010	54.480
Generator Sets	0.376	0.279	0.001	0.048	0.019	0.019	61.100
Graders	0.722	0.581	0.001	0.105	0.035	0.035	132.980
Off-Highway Tractors	1.229	0.676	0.002	0.163	0.058	0.058	151.779
Off-Highway Trucks	1.053	0.563	0.003	0.161	0.036	0.036	260.436
Other Construction Equipment	0.448	0.354	0.001	0.063	0.018	0.018	122.663
Other General Industrial Equipment	0.824	0.459	0.002	0.111	0.034	0.034	152.491
Other Material Handling Equipment	0.805	0.450	0.002	0.105	0.032	0.032	141.431
Pavers	0.624	0.502	0.001	0.112	0.042	0.042	78.186
Paving Equipment	0.556	0.414	0.001	0.086	0.037	0.037	69.134
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.070	0.056	0.000	0.010	0.004	0.004	9.436
Pumps	0.331	0.272	0.001	0.046	0.019	0.019	49.710
Rollers	0.448	0.388	0.001	0.068	0.029	0.029	67.198
Rough Terrain Forklifts	0.422	0.450	0.001	0.064	0.028	0.028	70.425
Rubber Tired Dozers	1.819	0.882	0.002	0.234	0.074	0.074	239.616
Rubber Tired Loaders	0.583	0.447	0.001	0.086	0.030	0.030	108.805
Scrapers	1.604	0.842	0.003	0.214	0.065	0.065	262.969
Signal Boards	0.103	0.092	0.000	0.014	0.005	0.005	16.730
Skid Steer Loaders	0.180	0.215	0.000	0.025	0.007	0.007	30.335
Surfacing Equipment	0.804	0.419	0.002	0.092	0.029	0.029	166.175
Sweepers/Scrubbers	0.431	0.495	0.001	0.068	0.025	0.025	78.697
Tractors/Loaders/Backhoes	0.333	0.365	0.001	0.051	0.019	0.019	66.913
Trenchers	0.512	0.437	0.001	0.106	0.039	0.039	58.953
Welders	0.194		0.000	0.039	0.013	0.013	25.690

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-7. Criteria Pollutant Emission Factors for Off-Road Equipment - 2019

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.200	0.172	0.000	0.029	0.010	0.010	34.787
Air Compressors	0.358	0.310	0.001	0.053	0.021	0.021	63.726
Bore/Drill Rigs	0.376	0.501	0.002	0.051	0.008	0.008	164.985
Cement and Mortar Mixers	0.054	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.367	0.381	0.001	0.054	0.023	0.023	58.585
Cranes	0.724	0.398	0.001	0.095	0.029	0.029	128.844
Crawler Tractors	0.735	0.532	0.001	0.111	0.042	0.042	114.269
Crushing/Proc. Equipment	0.662	0.628	0.001	0.101	0.036	0.036	132.537
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.457	0.514	0.001	0.079	0.021	0.021	119.757
Forklifts	0.192	0.217	0.001	0.034	0.009	0.009	54.474
Generator Sets	0.348	0.276	0.001	0.043	0.017	0.017	61.090
Graders	0.649	0.579	0.001	0.098	0.032	0.032	132.965
Off-Highway Tractors	1.145	0.663	0.002	0.155	0.054	0.054	151.756
Off-Highway Trucks	0.935	0.557	0.003	0.152	0.032	0.032	260.430
Other Construction Equipment	0.397	0.352	0.001	0.060	0.016	0.016	122.638
Other General Industrial Equipment	0.742	0.455	0.002	0.104	0.030	0.030	152.475
Other Material Handling Equipment	0.724	0.446	0.002	0.098	0.029	0.029	141.416
Pavers	0.583	0.497	0.001	0.105	0.039	0.039	78.171
Paving Equipment	0.517	0.411	0.001	0.081	0.034	0.034	69.121
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.068	0.055	0.000	0.009	0.003	0.003	9.434
Pumps	0.307	0.269	0.001	0.041	0.017	0.017	49.700
Rollers	0.413	0.386	0.001	0.063	0.026	0.026	67.185
Rough Terrain Forklifts	0.383	0.448	0.001	0.058	0.024	0.024	70.411
Rubber Tired Dozers	1.695	0.839	0.002	0.223	0.068	0.068	239.588
Rubber Tired Loaders	0.527	0.444	0.001	0.080	0.027	0.027	108.792
Scrapers	1.469	0.816	0.003	0.202	0.059	0.059	262.942
Signal Boards	0.097	0.091	0.000	0.014	0.005	0.005	16.729
Skid Steer Loaders	0.170	0.213	0.000	0.024	0.006	0.006	30.331
Surfacing Equipment	0.729	0.406	0.002	0.087	0.026	0.026	166.161
Sweepers/Scrubbers	0.392	0.493	0.001	0.063	0.022	0.022	78.686
Tractors/Loaders/Backhoes	0.302	0.363	0.001	0.047	0.016	0.016	66.904
Trenchers	0.484	0.432	0.001	0.100	0.036	0.036	58.938
Welders	0.183	0.184	0.000	0.034	0.012	0.012	25.680

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-8. Criteria Pollutant Emission Factors for Off-Road Equipment - 2020

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.187	0.170	0.000	0.026	0.009	0.009	34.781
Air Compressors	0.325	0.308	0.001	0.048	0.018	0.018	63.716
Bore/Drill Rigs	0.344	0.501	0.002	0.048	0.006	0.006	164.970
Cement and Mortar Mixers	0.054	0.042	0.000	0.009	0.002	0.002	7.268
Concrete/Industrial Saws	0.341	0.378	0.001	0.048	0.020	0.020	58.573
Cranes	0.661	0.392	0.001	0.090	0.026	0.026	128.833
Crawler Tractors	0.677	0.526	0.001	0.105	0.038	0.038	114.254
Crushing/Proc. Equipment	0.598	0.625	0.001	0.093	0.031	0.031	132.519
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.404	0.512	0.001	0.073	0.018	0.018	119.745
Forklifts	0.169	0.216	0.001	0.032	0.007	0.007	54.468
Generator Sets	0.323	0.273	0.001	0.040	0.015	0.015	61.082
Graders	0.582	0.577	0.001	0.092	0.028	0.028	132.950
Off-Highway Tractors	1.066	0.652	0.002	0.147	0.050	0.050	151.735
Off-Highway Trucks	0.831	0.551	0.003	0.144	0.028	0.028	260.413
Other Construction Equipment	0.352	0.351	0.001	0.056	0.014	0.014	122.624
Other General Industrial Equipment	0.666	0.452	0.002	0.098	0.026	0.026	152.462
Other Material Handling Equipment	0.650	0.443	0.002	0.092	0.025	0.025	141.403
Pavers	0.545	0.492	0.001	0.099	0.035	0.035	78.156
Paving Equipment	0.481	0.408	0.001	0.076	0.032	0.032	69.110
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.065	0.055	0.000	0.009	0.003	0.003	9.433
Pumps	0.285	0.267	0.001	0.038	0.015	0.015	49.691
Rollers	0.379	0.384	0.001	0.058	0.023	0.023	67.172
Rough Terrain Forklifts	0.349	0.446	0.001	0.053	0.020	0.020	70.401
Rubber Tired Dozers	1.577	0.801	0.002	0.212	0.063	0.063	239.562
Rubber Tired Loaders	0.475	0.441	0.001	0.075	0.023	0.023	108.781
Scrapers	1.343	0.794	0.003	0.191	0.054	0.054	262.917
Signal Boards	0.091	0.091	0.000	0.013	0.004	0.004	16.727
Skid Steer Loaders	0.161	0.213	0.000	0.022	0.005	0.005	30.327
Surfacing Equipment	0.659	0.395	0.002	0.082	0.024	0.024	166.149
Sweepers/Scrubbers	0.356	0.492	0.001	0.058	0.018	0.018	78.675
Tractors/Loaders/Backhoes	0.274	0.362	0.001	0.044	0.013	0.013	66.897
Trenchers	0.458	0.427	0.001	0.093	0.034	0.034	58.924
Welders	0.173	0.182	0.000	0.031	0.010	0.010	25.673

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-9. Criteria Pollutant Emission Factors for Off-Road Equipment - 2021

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.173	0.168	0.000	0.024	0.008	0.008	34.775
Air Compressors	0.293	0.305	0.001	0.044	0.016	0.016	63.707
Bore/Drill Rigs	0.322	0.501	0.002	0.046	0.005	0.005	164.993
Cement and Mortar Mixers	0.054	0.041	0.000	0.009	0.002	0.002	7.267
Concrete/Industrial Saws	0.318	0.376	0.001	0.044	0.017	0.017	58.564
Cranes	0.603	0.387	0.001	0.085	0.023	0.023	128.822
Crawler Tractors	0.624	0.521	0.001	0.099	0.034	0.034	114.240
Crushing/Proc. Equipment	0.541	0.622	0.001	0.087	0.027	0.027	132.505
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.358	0.511	0.001	0.069	0.016	0.016	119.734
Forklifts	0.146	0.215	0.001	0.029	0.006	0.006	54.462
Generator Sets	0.298	0.271	0.001	0.036	0.013	0.013	61.075
Graders	0.521	0.575	0.001	0.086	0.025	0.025	132.937
Off-Highway Tractors	0.990	0.641	0.002	0.139	0.046	0.046	151.714
Off-Highway Trucks	0.738	0.548	0.003	0.137	0.025	0.025	260.392
Other Construction Equipment	0.312	0.350	0.001	0.053	0.012	0.012	122.618
Other General Industrial Equipment	0.589	0.448	0.002	0.091	0.023	0.023	152.446
Other Material Handling Equipment	0.575	0.439	0.002	0.086	0.022	0.022	141.388
Pavers	0.509	0.488	0.001	0.093	0.032	0.032	78.142
Paving Equipment	0.446	0.406	0.001	0.071	0.029	0.029	69.099
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.063	0.054	0.000	0.008	0.003	0.003	9.431
Pumps	0.264	0.265	0.001	0.034	0.013	0.013	49.684
Rollers	0.348	0.382	0.001	0.054	0.021	0.021	67.160
Rough Terrain Forklifts	0.319	0.445	0.001	0.050	0.017	0.017	70.393
Rubber Tired Dozers	1.466	0.766	0.002	0.202	0.058	0.058	239.537
Rubber Tired Loaders	0.427	0.438	0.001	0.071	0.021	0.021	108.770
Scrapers	1.226	0.775	0.003	0.181	0.049	0.049	262.894
Signal Boards	0.086	0.091	0.000	0.012	0.004	0.004	16.726
Skid Steer Loaders	0.154	0.212	0.000	0.021	0.004	0.004	30.324
Surfacing Equipment	0.595	0.386	0.002	0.078	0.022	0.022	166.139
Sweepers/Scrubbers	0.323	0.488	0.001	0.054	0.015	0.015	78.664
Tractors/Loaders/Backhoes	0.251	0.361	0.001	0.041	0.011	0.011	66.891
Trenchers	0.433	0.423	0.001	0.087	0.031	0.031	58.910
Welders	0.163	0.179	0.000	0.028	0.009	0.009	25.666

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-10. Criteria Pollutant Emission Factors for Off-Road Equipment - 2022

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.162	0.167	0.000	0.022	0.007	0.007	34.772
Air Compressors	0.268	0.304	0.001	0.041	0.014	0.014	63.701
Bore/Drill Rigs	0.306	0.501	0.002	0.045	0.005	0.005	164.992
Cement and Mortar Mixers	0.053	0.041	0.000	0.009	0.002	0.002	7.267
Concrete/Industrial Saws	0.296	0.374	0.001	0.041	0.015	0.015	58.556
Cranes	0.551	0.382	0.001	0.080	0.020	0.020	128.811
Crawler Tractors	0.575	0.516	0.001	0.093	0.031	0.031	114.227
Crushing/Proc. Equipment	0.491	0.621	0.001	0.082	0.023	0.023	132.493
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.317	0.510	0.001	0.065	0.014	0.014	119.726
Forklifts	0.127	0.215	0.001	0.027	0.004	0.004	54.458
Generator Sets	0.278	0.269	0.001	0.034	0.012	0.012	61.069
Graders	0.466	0.573	0.001	0.081	0.022	0.022	132.925
Off-Highway Tractors	0.919	0.632	0.002	0.132	0.042	0.042	151.694
Off-Highway Trucks	0.657	0.545	0.003	0.130	0.022	0.022	260.373
Other Construction Equipment	0.279	0.349	0.001	0.051	0.011	0.011	122.619
Other General Industrial Equipment	0.530	0.446	0.002	0.087	0.020	0.020	152.435
Other Material Handling Equipment	0.516	0.438	0.002	0.081	0.019	0.019	141.377
Pavers	0.475	0.484	0.001	0.087	0.030	0.030	78.129
Paving Equipment	0.414	0.404	0.001	0.067	0.026	0.026	69.088
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.061	0.054	0.000	0.008	0.002	0.002	9.431
Pumps	0.247	0.264	0.001	0.032	0.011	0.011	49.679
Rollers	0.320	0.380	0.001	0.050	0.018	0.018	67.149
Rough Terrain Forklifts	0.292	0.445	0.001	0.047	0.015	0.015	70.386
Rubber Tired Dozers	1.361	0.735	0.002	0.192	0.054	0.054	239.515
Rubber Tired Loaders	0.385	0.436	0.001	0.066	0.018	0.018	108.760
Scrapers	1.118	0.758	0.003	0.172	0.045	0.045	262.872
Signal Boards	0.082	0.091	0.000	0.012	0.004	0.004	16.725
Skid Steer Loaders	0.148	0.211	0.000	0.020	0.003	0.003	30.322
Surfacing Equipment	0.537	0.378	0.002	0.074	0.020	0.020	166.131
Sweepers/Scrubbers	0.295	0.487	0.001	0.050	0.012	0.012	78.656
Tractors/Loaders/Backhoes	0.230	0.360	0.001	0.038	0.010	0.010	66.885
Trenchers	0.409	0.419	0.001	0.082	0.028	0.028	58.897
Welders	0.156	0.177	0.000	0.026	0.008	0.008	25.661

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-11. Criteria Pollutant Emission Factors for Off-Road Equipment - 2023

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.152	0.166	0.000	0.021	0.006	0.006	34.769
Air Compressors	0.246	0.303	0.001	0.039	0.012	0.012	63.695
Bore/Drill Rigs	0.295	0.501	0.002	0.044	0.005	0.005	164.983
Cement and Mortar Mixers	0.053	0.041	0.000	0.009	0.002	0.002	7.267
Concrete/Industrial Saws	0.277	0.373	0.001	0.038	0.013	0.013	58.550
Cranes	0.503	0.379	0.001	0.075	0.018	0.018	128.799
Crawler Tractors	0.529	0.513	0.001	0.088	0.028	0.028	114.215
Crushing/Proc. Equipment	0.448	0.620	0.001	0.077	0.020	0.020	132.482
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.282	0.510	0.001	0.061	0.012	0.012	119.718
Forklifts	0.111	0.215	0.001	0.026	0.003	0.003	54.454
Generator Sets	0.261	0.268	0.001	0.032	0.010	0.010	61.065
Graders	0.416	0.572	0.001	0.076	0.019	0.019	132.914
Off-Highway Tractors	0.852	0.624	0.002	0.126	0.039	0.039	151.676
Off-Highway Trucks	0.588	0.542	0.003	0.124	0.019	0.019	260.354
Other Construction Equipment	0.250	0.348	0.001	0.048	0.009	0.009	122.618
Other General Industrial Equipment	0.481	0.445	0.002	0.082	0.017	0.017	152.426
Other Material Handling Equipment	0.467	0.437	0.002	0.077	0.017	0.017	141.368
Pavers	0.443	0.480	0.001	0.082	0.027	0.027	78.117
Paving Equipment	0.383	0.402	0.001	0.062	0.024	0.024	69.078
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.059	0.054	0.000	0.007	0.002	0.002	9.430
Pumps	0.232	0.263	0.001	0.030	0.010	0.010	49.675
Rollers	0.294	0.378	0.001	0.046	0.016	0.016	67.140
Rough Terrain Forklifts	0.269	0.444	0.001	0.044	0.013	0.013	70.380
Rubber Tired Dozers	1.262	0.708	0.002	0.183	0.049	0.049	239.493
Rubber Tired Loaders	0.347	0.434	0.001	0.062	0.016	0.016	108.752
Scrapers	1.017	0.743	0.003	0.164	0.041	0.041	262.853
Signal Boards	0.078	0.091	0.000	0.012	0.003	0.003	16.725
Skid Steer Loaders	0.143	0.211	0.000	0.020	0.003	0.003	30.319
Surfacing Equipment	0.484	0.371	0.002	0.070	0.018	0.018	166.125
Sweepers/Scrubbers	0.269	0.485	0.001	0.046	0.010	0.010	78.648
Tractors/Loaders/Backhoes	0.213	0.359	0.001	0.036	0.008	0.008	66.880
Trenchers	0.388	0.415	0.001	0.077	0.026	0.026	58.885
Welders	0.149	0.176	0.000	0.024	0.007	0.007	25.657

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-12. Criteria Pollutant Emission Factors for Off-Road Equipment - 2024

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.144	0.165	0.000	0.020	0.005	0.005	34.766
Air Compressors	0.227	0.303	0.001	0.037	0.010	0.010	63.690
Bore/Drill Rigs	0.289	0.501	0.002	0.043	0.004	0.004	164.975
Cement and Mortar Mixers	0.053	0.041	0.000	0.009	0.002	0.002	7.267
Concrete/Industrial Saws	0.261	0.372	0.001	0.036	0.011	0.011	58.544
Cranes	0.460	0.376	0.001	0.072	0.016	0.016	128.788
Crawler Tractors	0.487	0.509	0.001	0.083	0.025	0.025	114.204
Crushing/Proc. Equipment	0.410	0.619	0.001	0.073	0.017	0.017	132.473
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.252	0.509	0.001	0.058	0.010	0.010	119.711
Forklifts	0.097	0.215	0.001	0.025	0.003	0.003	54.451
Generator Sets	0.246	0.267	0.001	0.030	0.009	0.009	61.061
Graders	0.371	0.571	0.001	0.071	0.017	0.017	132.904
Off-Highway Tractors	0.788	0.617	0.002	0.119	0.036	0.036	151.659
Off-Highway Trucks	0.529	0.540	0.003	0.119	0.016	0.016	260.338
Other Construction Equipment	0.224	0.348	0.001	0.046	0.008	0.008	122.614
Other General Industrial Equipment	0.436	0.445	0.002	0.078	0.015	0.015	152.417
Other Material Handling Equipment	0.424	0.436	0.002	0.073	0.015	0.015	141.359
Pavers	0.414	0.477	0.001	0.076	0.024	0.024	78.105
Paving Equipment	0.355	0.401	0.001	0.058	0.021	0.021	69.069
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.057	0.053	0.000	0.007	0.002	0.002	9.429
Pumps	0.219	0.262	0.001	0.029	0.009	0.009	49.671
Rollers	0.271	0.377	0.001	0.043	0.014	0.014	67.131
Rough Terrain Forklifts	0.250	0.443	0.001	0.042	0.011	0.011	70.375
Rubber Tired Dozers	1.170	0.683	0.002	0.175	0.045	0.045	239.473
Rubber Tired Loaders	0.313	0.432	0.001	0.059	0.014	0.014	108.744
Scrapers	0.924	0.730	0.003	0.156	0.037	0.037	262.836
Signal Boards	0.075	0.091	0.000	0.011	0.003	0.003	16.724
Skid Steer Loaders	0.139	0.211	0.000	0.019	0.002	0.002	30.318
Surfacing Equipment	0.436	0.364	0.002	0.067	0.016	0.016	166.120
Sweepers/Scrubbers	0.246	0.485	0.001	0.043	0.008	0.008	78.641
Tractors/Loaders/Backhoes	0.198	0.359	0.001	0.035	0.007	0.007	66.876
Trenchers	0.367	0.412	0.001	0.072	0.024	0.024	58.874
Welders	0.143	0.175	0.000	0.023	0.006	0.006	25.654

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

Table 4-13. Criteria Pollutant Emission Factors for Off-Road Equipment - 2025

Equipment	Emission Factors (lb/hr)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀ ⁽²⁾	PM _{2.5} ⁽²⁾	GHG ³
Aerial Lifts	0.137	0.165	0.000	0.018	0.005	0.005	34.763
Air Compressors	0.210	0.303	0.001	0.035	0.009	0.009	63.686
Bore/Drill Rigs	0.286	0.501	0.002	0.043	0.004	0.004	164.964
Cement and Mortar Mixers	0.053	0.041	0.000	0.009	0.002	0.002	7.267
Concrete/Industrial Saws	0.247	0.371	0.001	0.034	0.009	0.009	58.540
Cranes	0.422	0.374	0.001	0.068	0.014	0.014	128.778
Crawler Tractors	0.449	0.506	0.001	0.079	0.023	0.023	114.195
Crushing/Proc. Equipment	0.376	0.619	0.001	0.069	0.015	0.015	132.464
Dumpers/Tenders	0.058	0.031	0.000	0.009	0.002	0.002	7.645
Excavators	0.227	0.509	0.001	0.056	0.009	0.009	119.705
Forklifts	0.086	0.215	0.001	0.024	0.003	0.003	54.449
Generator Sets	0.233	0.267	0.001	0.029	0.008	0.008	61.058
Graders	0.331	0.570	0.001	0.068	0.015	0.015	132.896
Off-Highway Tractors	0.729	0.610	0.002	0.113	0.033	0.033	151.643
Off-Highway Trucks	0.477	0.538	0.003	0.114	0.014	0.014	260.322
Other Construction Equipment	0.202	0.347	0.001	0.044	0.007	0.007	122.605
Other General Industrial Equipment	0.395	0.444	0.002	0.075	0.013	0.013	152.408
Other Material Handling Equipment	0.384	0.436	0.002	0.070	0.012	0.012	141.351
Pavers	0.386	0.474	0.001	0.072	0.022	0.022	78.094
Paving Equipment	0.328	0.399	0.001	0.055	0.019	0.019	69.060
Plate Compactors	0.031	0.026	0.000	0.005	0.001	0.001	4.325
Pressure Washers	0.056	0.053	0.000	0.007	0.002	0.002	9.428
Pumps	0.208	0.262	0.001	0.027	0.008	0.008	49.667
Rollers	0.250	0.376	0.001	0.041	0.012	0.012	67.123
Rough Terrain Forklifts	0.234	0.443	0.001	0.040	0.009	0.009	70.370
Rubber Tired Dozers	1.082	0.662	0.002	0.167	0.042	0.042	239.455
Rubber Tired Loaders	0.283	0.431	0.001	0.056	0.012	0.012	108.737
Scrapers	0.839	0.719	0.003	0.150	0.033	0.033	262.820
Signal Boards	0.072	0.091	0.000	0.011	0.003	0.003	16.723
Skid Steer Loaders	0.135	0.210	0.000	0.019	0.002	0.002	30.316
Surfacing Equipment	0.392	0.359	0.002	0.064	0.014	0.014	166.115
Sweepers/Scrubbers	0.225	0.484	0.001	0.041	0.006	0.006	78.636
Tractors/Loaders/Backhoes	0.186	0.359	0.001	0.034	0.006	0.006	66.872
Trenchers	0.348	0.409	0.001	0.067	0.022	0.022	58.864
Welders	0.137	0.175	0.000	0.021	0.005	0.005	25.651

SOURCE: "Software User's Guide: URBEMIS2007 for Windows," South Coast Air Quality Management District (SCAQMD), November 2007. All emission factors converted into units of lb/hr and multiplied by the average load factor for each equipment type as estimated in URBEMIS.

1. Source provides emission factors for ROG which are assumed to be equal to VOC.
2. Source provides emission factors for total particulate which is conservatively assumed to be equal to PM₁₀ and PM_{2.5}.
3. Greenhouse gas (GHG) emission factor is the sum of the product of CO₂ and CH₄ and their respective Global Warming Potentials (GWP). GWP for CO₂ and CH₄ are 1 and 25 respectively.

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 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

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5 PORTABLE AND SEASONAL RECIPROCATING INTERNAL COMBUSTION ENGINES

➤ *Point Source*

5.1 Introduction

Each Air Force base uses portable Reciprocating Internal Combustion Engines (RICE) equipment (not self-propelled) for short-term needs and seasonal activities. These portable RICE 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 Stationary Guide, but are outlined here.

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 are able to 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. 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. Fuel is added to the heated air and combusts due to the fact that the temperature of the air is above the auto-ignition temperature of the fuel. Spark ignition (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 which 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 greenhouse gases (GHG). A simple control volume describing the emissions from portable RICE equipment is provided in Figure 5-1.

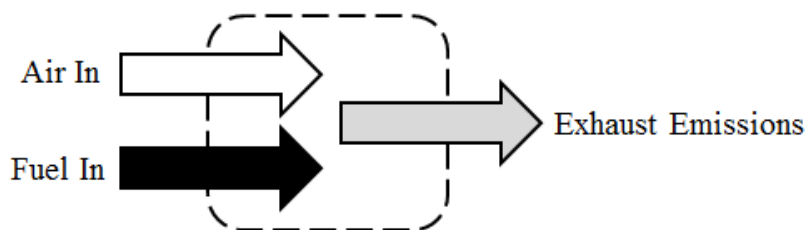


Figure 5-1. Simplified Portable RICE Control Volume

5.2 NESHAP & NSPS Applicability

Internal combustion engines comprise a large list of pollutant emitting equipment. The number of devices which fall into this category (both stationary and non-stationary) has led to the rise of several standards to help minimize the volume of emissions produced. One New Source Performance Standard (NSPS), which is given in 40 CFR 60 subpart IIII, provides performance standards applicable to manufacturers, owners, and operators of diesel engines with a displacement of less than 30 liters per cylinder. These standards outline the emissions limits for criteria pollutants for diesel engines based on horsepower. Similarly, 40 CFR 60 subpart JJJJ provides emissions limits for spark ignition reciprocating internal combustion engines based on horsepower and manufacture date.

In addition to the new source performance standards, a National Emission Standard for Hazardous Air Pollutants (NESHAPs) has also been developed for stationary reciprocating internal combustion engines at facilities which are major sources of HAP emissions. 40 CFR 63 subpart ZZZZ outlines the emission limits and operational limits for both spark and compression ignition reciprocating internal combustion engines. Consult the section above in the Code of Federal Regulations (CFR) for more information or to verify that the engines located on site are in compliance with these standards.

5.3 Emission Factors

Chapter 3 of AP-42 provides emission factors for RICE based on the fuel used and size of the equipment. However, increasingly stringent emissions requirements have driven the manufacture of engines that produce far less emissions than those engines which served as a basis for the

development of the emission factors found in AP-42. Though these emission factors 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 emission factors 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. These NSPS thresholds were proposed to set standards for newly manufactured engines as well as older engines which have been rebuilt or modified.

For the purpose of emissions calculations for portable RICE, the emission factors provided were selected from AP-42 or are emissions thresholds as set by the NSPS. Any NSPS emission thresholds (which all new or reconstructed engines must comply with) that are less than the emission factor provided in AP-42 were used for RICE emission values. If the NSPS emission threshold was greater than the emission factors in AP-42, then the AP-42 values were used since these are based on actual test data.

Emissions estimates may be made based on the heating value or sulfur content of the fuels used to operate the RICE. **Typical fuel data and RICE emission factors for portable use equipment are provided in the “Stationary Internal Combustion” section of the Stationary Guide.** For simplicity, the emission factors are provided for two time-spans for engines manufactured prior to 2007 (or 2011 for engines >3000hp and displacement $\leq 10\text{L/cylinder}$) and those engines manufactured or modified after this date. Though this simplification may lead to reduced emissions than if using AP-42 emission factors, it is possible to reduce emissions further by consulting the CFRs directly to determine additional thresholds and implementation years not given.

5.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. There are two methods for estimating emissions from emergency equipment use – the fuel consumption method and the load factor method. Both are described below.

5.4.1 Fuel Consumption Method

The fuel consumption method is the simplest method for calculating the emissions from emergency use engines because all that is needed is the total fuel consumed by that engine and the emission factor associated with the type of engine and fuel used. The emissions are calculated as follows:

$$E_{Pol} = Q \times HV \times \frac{1}{10^6} \times EF_{Pol}$$

Equation 5-1

Where,

- E_{Pol}** = Annual emissions of pollutant (lb/yr)
- Q** = Annual quantity of fuel consumed (gal/yr) or (ft³/yr)
- HV** = Heating value of the fuel used (Btu/gal) or (Btu/ft³)
- 10⁶** = Factor to convert Btu to MMBtu (MMBtu/Btu)
- EF_{Pol}** = Emission factor from Stationary Guide (lb/MMBtu)

A detailed representation of the emissions from stationary ICOM engines is provided in Figure 5-2.

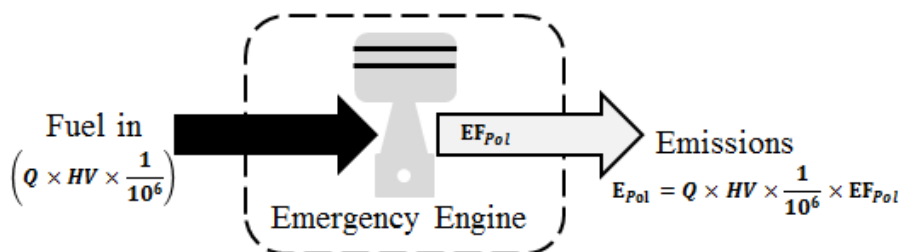


Figure 5-2. Emergency Equipment Use Control Volume - Fuel Consumption Method

5.4.2 Load Factor Method

To calculate the most accurate emissions for emergency use engines, the first step is to gather the required data and select the appropriate emission factor. **To use the load factor method, the engine's rated power, operating time, and typical load factor must be known. Actual site-specific loading factors should be used whenever possible.** With the selected emission factor and loading factor, the ICOM emissions are calculated using the following equation:

$$E_{Pol} = OT \times PO \times \frac{LF}{100} \times EF_{Pol}$$

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)
- EF_{Pol}** = Emission factor from the Stationary Guide (lb/hp-hr)

A detailed representation of the emissions from emergency equipment use is provided in Figure 5-3.

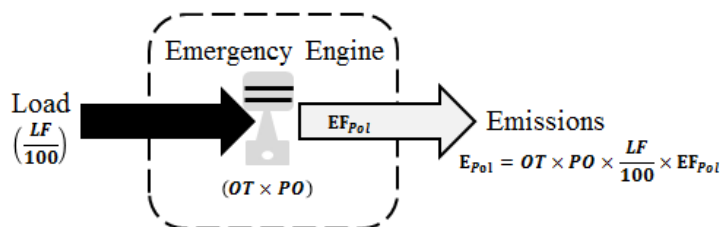


Figure 5-3. Emergency Equipment Use Control Volume - Load Factor Method

5.5 Information Resources

All emission factors presented are conservative by necessity since each applies to a large range of equipment sizes and designs. For data required for emissions calculations, contact the group responsible for operating/maintaining the emergency equipment on base, typically Civil Engineering, and consult the Equipment Specification (Data or Spec) Sheets or contact the manufacturer directly. Since the emission factors provided are applicable to a wide range of equipment sizes, the accuracy of emissions calculations may be enhanced by reviewing the CFR to determine the emissions thresholds of each pollutant for emergency-use engines found on base. Alternatively, the manufacturer may be contacted to request any emissions data they may have on file for those engine models. Additionally, if the engine's Brake Specific Fuel Consumption (BSFC) is available, either through the spec sheet or from the manufacturer, then that value should be used for emission factor 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 used at that installation. These sulfur content values should then be used in place of the averages provided in the Stationary Guide.

5.6 Example Problem

5.6.1 Problem #1 - Fuel Consumption Method

Anytown AFB is looking to determine the NO_x emissions from a diesel-fired fire pump for the previous year. Determine the NO_x emissions from this fire pump for last year using the fuel consumption method. This installation is not 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 2.1L per cylinder.

Step 1 – Select and Record Emission Factor and fuel Heating Value. The emission factors for diesel-fired engines are provided in the Stationary Guide. The NO_x emission factor is 4.41E+00 lb/MMBtu. Also, the heating value of diesel is shown to be 138,000 Btu/gal.

Step 2 – Choose a calculation method and record the appropriate equation. For demonstration purposes, the method was already assigned in the problem statement, however, it should be recognized 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 given. The formula for the fuel consumption method is:

$$E_{Pol} = Q \times HV \times \frac{1}{10^6} \times EF_{Pol}$$

Step 3 – Calculate Emissions. Using the fuel quantity data and emission factor, NO_x emissions may be calculated using Equation 5-1.

$$E_{NO_x} = 12 \left(\frac{\text{gal}}{\text{yr}} \right) \times 138,000 \left(\frac{\text{Btu}}{\text{gal}} \right) \times \frac{1}{10^6} \left(\frac{\text{MMBtu}}{\text{Btu}} \right) \times 4.41 \left(\frac{\text{lb}}{\text{MMBtu}} \right)$$

$$E_{NO_x} = 1,656,000 \left(\frac{\text{Btu}}{\text{yr}} \right) \times \frac{1}{10^6} \left(\frac{\text{MMBtu}}{\text{Btu}} \right) \times 4.41 \left(\frac{\text{lb}}{\text{MMBtu}} \right)$$

$$E_{NO_x} = 1.656 \left(\frac{\text{MMBtu}}{\text{yr}} \right) \times 4.41 \left(\frac{\text{lb}}{\text{MMBtu}} \right)$$

$$E_{NO_x} = 7.30 \frac{\text{lb}}{\text{yr}}$$

5.6.2 Problem #2 - Load Factor Method

Anytown AFB must calculate emissions from a stationary diesel-fired generator. Calculate the VOC emitted by this generator from last year using the load factor method. The installation is not located in Alaska. The generator was manufactured in 2004, and operated for 22 hours last year. The generator spec sheet shows it is 1250hp and the engine has a displacement of 2.0L per cylinder. The typical load factor is approximately 74%.

Step 1 – Select and record emission factor. The emission factors are provided in the Stationary Guide. For a 1250hp diesel engine manufactured in 2004 with 2.0L per cylinder displacement, the VOC emission factor is **7.16E-04 lb/hp-hr**.

Step 2 – Choose a calculation method and record the appropriate equation. For demonstration purposes, the method was already assigned in the problem statement. The formula for the load factor method is:

$$E_{Pol} = OT \times PO \times \frac{LF}{100} \times EF_{Pol}$$

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

$$E_{VOC} = 22 \left(\frac{hr}{yr} \right) \times 1250(hp) \times \frac{74\%}{100\%} \times 0.000716 \left(\frac{lb}{hp-hr} \right)$$

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

$$\boxed{E_{VOC} = 14.57 \frac{lb}{yr}}$$

5.7 References

40 CFR 60 Subpart IIII, "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 IIII-Standards of Performance for Stationary Compression Ignition Internal Combustion Engines," U.S. Environmental Protection Agency

40 CFR 60 Subpart JJJJ, "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 JJJJ-Standards of Performance for Stationary Spark Ignition Internal Combustion Engines," U.S. Environmental Protection Agency

40 CFR 63 Subpart YYYY, "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 YYYY-National Emission Standards for Hazardous Air Pollutants for Stationary Combustion Turbines," U.S. Environmental Protection Agency

40 CFR 63 Subpart ZZZZ, "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 ZZZZ-National Emissions Standards for Hazardous Air Pollutants for Stationary Reciprocating Internal Combustion Engines," U.S. Environmental Protection Agency

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 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 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., et al, "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

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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 a result of transfer incidents. The most common spills involve fuels transferred on base including diesel, gasoline or JP-8 and, to a lesser extent, propane and Avgas. 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.

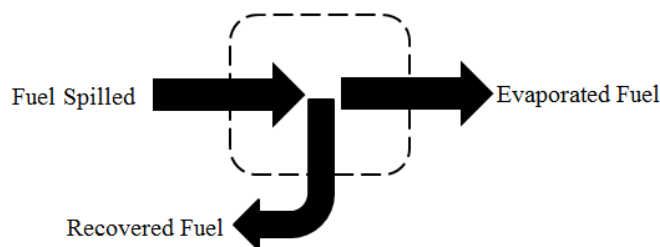


Figure 6-1. Simplified Fuel Spill Control Volume

6.2 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. Emission factors 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 Calculation

VOC emissions from spills are calculated using Equation 6-1.

$$E_{VOC} = (Q_S - Q_R) \times SG \times 8.33$$

Equation 6-1

Where,

E_{VOC} = Annual emissions of VOC from spills (lb/yr)

Q_S = Annual quantity of liquid spilled (gal/yr)

Q_R = Annual quantity of liquid recovered (gal/yr)

SG = Specific gravity of liquid

8.33 = Density of water at 70°F (lb/gal).

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

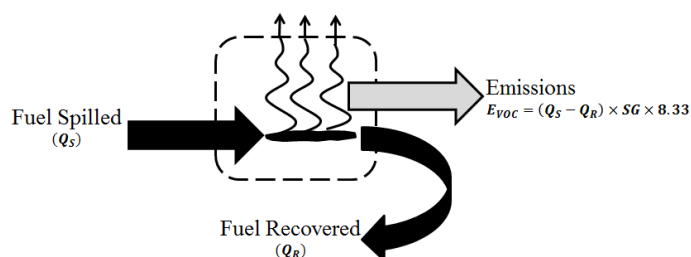


Figure 6-2. Fuel Spill Control Volume

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 Fuel Commonly Used at Air Force Installations

Fuel Type	Density (lb/gal)
Diesel	7.14
MOGAS	6.15
Jet A/JP-8	6.67 ⁽¹⁾
LPG	4.41

SOURCE (unless otherwise noted): "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

1. SOURCE: "Petroleum Quality Information System Fuels Data (2005)," Defense Logistics Agency (DLA), Defense Energy Support Center, Technology and Standardization Division, 2006

6.2.2 HAP Emissions Calculation

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 Equation 6-2.

$$E_{HAP} = E_{VOC} \times \left(\frac{WP_{HAP}}{100} \right)$$

Equation 6-2

Where,

- E_{HAP}** = Annual emissions of specific HAP (lb/yr)
E_{VOC} = Annual emissions of VOC as calculated in Equation 6-1 (lb/yr)
WP_{HAP} = Weight percent of the HAP in the liquid fuel (%)
100 = Factor converting weight percent to a weight fraction (%)

As with fuel density, there is some variation in the HAP weight percent between fuels. Contact the fuel supplier or review the MSDS for guidance in determining the correct weight percent for each HAP constituent in order 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	Typical Wt. %			
	In Diesel	In Gasoline	In Jet A/JP-8 ⁽¹⁾	In LPG ²
Anthracene	2.83E-03 ⁽²⁾	---	---	---
Benzene	8.00E-04	1.80E+00	3.38E-02	---
1,3-Butadiene	---	2.00E-04 ⁽²⁾	---	2.17E-02
Cumene (Isopropyl benzene)	---	5.00E-01	1.81E-01	---
Dibenzofuran	1.64E-02 ⁽²⁾	---	---	---
Ethylbenzene	1.30E-02	1.40E+00	1.59E-01	---
Fluorene	2.94E-02 ⁽²⁾	---	3.44E-03	---
Hexane	1.00E-04	1.00E+00	---	3.46E-02
Isooctane (2,2,4-Trimethyl Pentane)	---	4.00E+00	1.23E-03	---
Naphthalene	3.39E-01 ⁽²⁾	1.74E-01 ⁽²⁾	2.68E-01	---
Phenanthrene	3.22E-02 ⁽²⁾	---	---	---
Phenylbenzene (1,1'-biphenyl)	---	---	6.78E-02	---
Pyrene	3.62E-02 ⁽²⁾	---	1.00E-05	---
Toluene	3.20E-02	7.00E+00	2.19E-01	---
Xylenes (mixed isomers)	2.90E-01	7.00E+00	1.19E-02	---

SOURCE (Unless otherwise stated): wt. % values provided by TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005.

1. SOURCE: "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research Division, May 1996
 2. SOURCE: Values from the SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014
- "---" 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 is reported that there were 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 **6.67lb/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:

$$E_{VOC} = (Q_S - Q_R) \times D$$

$$E_{VOC} = \left(625 \frac{\text{gal}}{\text{yr}} - 450 \frac{\text{gal}}{\text{yr}} \right) \times 6.67 \frac{\text{lb}}{\text{gal}}$$

$$E_{VOC} = \left(175 \frac{\text{gal}}{\text{yr}} \right) \times 6.67 \frac{\text{lb}}{\text{gal}}$$

$$E_{VOC} = 1167.25 \frac{\text{lb}}{\text{yr}}$$

Step 3 – Select and record the wt. % of each HAP in JP-8. Using Table 6-2, the HAP constituents of JP-8 are: **benzene 3.38E-02, cumene 1.81E-01, ethylbenzene 1.59E-01, fluorene 3.44E-03, isooctane 1.23E-03, naphthalene 2.68E-01, phenylbenzene 6.78E-02, pyrene 1.00E-05, toluene 2.19E-01, and xylene 1.19E-02.**

Step 4 – Calculate emissions of each HAP. HAP emission 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.

$$E_{HAP} = E_{VOC} \times \left(\frac{WP_{HAP}}{100} \right)$$

$$E_{Benzene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.0338\%}{100\%} \right)$$

$$E_{Benzene} = 1167.25 \frac{lb}{yr} \times (0.000338)$$

$$E_{Benzene} = \mathbf{0.39 \frac{lb}{yr}}$$

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

$$E_{Cumene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.181\%}{100\%} \right) = \mathbf{2.11 \frac{lb}{yr}}$$

$$E_{Ethylbenzene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.159\%}{100\%} \right) = \mathbf{1.86 \frac{lb}{yr}}$$

$$E_{Fluorene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.00344\%}{100\%} \right) = \mathbf{0.04 \frac{lb}{yr}}$$

$$E_{Iso-octane} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.00123\%}{100\%} \right) = \mathbf{0.01 \frac{lb}{yr}}$$

$$E_{Naphthalene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.268\%}{100\%} \right) = \mathbf{3.13 \frac{lb}{yr}}$$

$$E_{Phenylbenzene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.0678\%}{100\%} \right) = \mathbf{0.79 \frac{lb}{yr}}$$

$$E_{Pyrene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.00001\%}{100\%} \right) = \mathbf{0.0001 \frac{lb}{yr}}$$

$$E_{Toluene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.219\%}{100\%} \right) = \mathbf{2.56 \frac{lb}{yr}}$$

$$E_{Xylene} = 1167.25 \frac{lb}{yr} \times \left(\frac{0.0119\%}{100\%} \right) = \mathbf{0.14 \frac{lb}{yr}}$$

Step 4 – Calculate total HAPs emitted. Sum the HAPs calculated in Step 3.

$$E_{Total\ HAP} = \sum (E_{HAP_1} + E_{HAP_2} + \cdots + E_{HAP_n})$$

$$E_{Total\ HAP} = (2.11 + 1.86 + 0.04 + 0.01 + 3.13 + 0.79 + 0.0001 + 2.56 + 0.14) \frac{lb}{yr}$$

$E_{Total\ HAP} = \mathbf{10.64 \frac{lb}{yr}}$

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 a particular year. Emissions from hot mix asphalt plants are addressed here because they are usually temporary in nature. However, if the HMA plant is in place for longer than one year they must be considered a stationary source and 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.

A 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 Force 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 Stationary Guide. A graphical representation of emissions from HMA plants is provided in Figure 7-1.

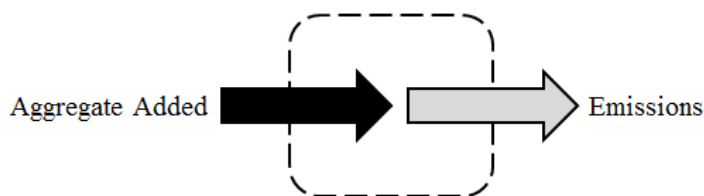


Figure 7-1. Simplified HMA Plants Emissions Control Volume

7.2 NSPS Applicability

Hot mix asphalt plants are subject to New Source Performance Standards (NSPS) as outlined in 40 CFR 60 subpart I. This section states that no hot mix asphalt plant shall emit more than 90mg/dscm of particulate matter or exhibit 20% or greater opacity. This section continues by outlining the requirements for proving that the facility is in compliance 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 Emission Factors

In all cases, utilizing site-specific stack sampling data with EPA Method 5 is the preferred method of estimating emissions from HMA operations. In the absence of such data, emission factors have been developed for production related fugitive and ducted emissions. Criteria pollutant emission factors are presented in Table 7-1 while speciated HAP emission factors are provided in Table 7-2. However, 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] ¹	PM _{2.5} [Controlled] ¹	GHG ²
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 9.80E-03 [FF]	2.70E-01 8.30E-03 [FF]	3.88E+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 9.80E-03 [FF]	2.70E-01 8.30E-03 [FF]	4.70E+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 9.80E-03 [FF]	2.70E-01 8.30E-03 [FF]	4.70E+01
Coal Fired [3-05-002-98]	---	---	4.30E-02	---	---	---	---	7.83E+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	6.40E+00 4.20E-03 [FF]	1.50E+00 2.90E-03 [FF]	3.49E+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	6.40E+00 4.20E-03 [FF]	1.50E+00 2.90E-03 [FF]	4.31E+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	6.40E+00 4.20E-03 [FF]	1.50E+00 2.90E-03 [FF]	4.31E+01
Coal Fired [3-05-002-98]	---	---	1.90E-01	---	---	---	---	7.43E+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

1. Control Device used: FF – Fabric Filter
2. GHG emission factors are the sum of the product of carbon dioxide (CO₂), Methane (CH₄), and nitrous oxide (N₂O) and their respective Global Warming Potentials (GWP). The GWP for CO₂, CH₄, and N₂O are 1, 25, and 298 respectively. Most emission factors taken from AP-42, however any missing data taken from “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.

“---” – Indicates No Data Available

Table 7-2. 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 (Hexavalent)	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-10	3.06E-10
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

7.4 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. Emissions may be calculated by multiplying the appropriate emission factor by the activity of the HMA production rate and the hours the plant was in operation during the year, as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

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.

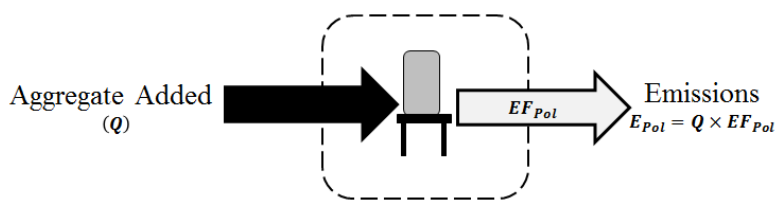


Figure 7-2. HMA Control Volume

7.5 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.

7.6 Example Problem

Anytown Air Force base needs to calculate formaldehyde emissions from their Hot Mix Asphalt 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 1100 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:

$$Q = \text{Max Production rate} \times \text{Operating Time}$$

$$Q = 190 \frac{\text{ton}}{\text{hr}} \times 1100 \frac{\text{hr}}{\text{yr}} = 209,000 \frac{\text{ton}}{\text{yr}}$$

Step 2 - Select and record the appropriate emission factor. Table 7-2 lists the emission factor 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 emission factor, Equation 7-1, and the information provided as follows:

$$E_{Pol} = Q \times EF_{Pol}$$

$$E_{Formaldehyde} = 0.00074 \frac{\text{lb}}{\text{ton}} \times 209,000 \frac{\text{ton}}{\text{yr}}$$

$$E_{Formaldehyde} = 154.66 \frac{\text{lb}}{\text{yr}}$$

7.7 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

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

8 SITE REMEDIATION (RDL)

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

8.1 Introduction

Air Force installations occasionally have sites that are contaminated with hazardous substances as a result of chemical leaks, spills, or prior disposal practices. 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 which 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 action/RCRA corrective actions, ERPMS must remain cognizant of, and comply with, certain requirements that are promulgated under the authority of other statutes (e.g., CAA, TSCA). 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.” CERCLA wastes 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.

8.2 Air Quality Regulatory Requirements

One objective of the CAA is to protect and enhance the quality of the nation’s air resources by regulating emission into the air through the National Ambient Air Quality Standards (NAAQS), the National Emission Standards for Hazardous Air Pollutants (NESHAP), and the New Source Performance Standards (NSPS). These standards may apply to both stationary and mobile sources of emissions and may be implemented through combined federal, state, and/or local programs. It is incumbent on Environmental Restoration Program Managers (ERPMS) overseeing CERCLA response actions/RCRA corrective actions that may result in emissions to the ambient air to

coordinate with the regulators' RCRA and air programs, as well as the EPA Regional Air/Superfund Coordinators to determine areas of responsibility and governing requirements.

Several technologies employed during ground remediation activities may result in new source emissions and may subject ERPMs to applicable or relevant and appropriate CAA requirements. Examples of these ground water remediation activities include:

- Air stripping,
- Thermal destruction (e.g., incineration, regeneration of spent activated carbon filters), management of contaminated ground water or recovered product (e.g., open-top tanks, surface impoundments),
- Surface impoundments),
- Gaseous waste treatment, and
- Biodegradation.

8.2.1 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, serious),
- Whether construction or modification of their stationary source commenced subsequent to the date of publication of regulations (or proposed regulations) prescribing a standard of performance that governs such source,
- Required control measures including emission limitations and emission 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)

8.2.2 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 hazardous air pollutants, 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 are stationary sources or a group of stationary sources located within a contiguous area and under 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 taken into account. 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 or management practices (GACT) 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 volatile organic compounds (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 particular 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 as 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, Lowest Achievable Emission Rates (LAERs)]. The six NAAQS are carbon monoxide, lead, nitrogen dioxide, particulate matter (PM-10), ozone, and sulfur dioxide. 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.]

8.2.3 NAAS Enforceability

Further, NAAQS are not enforceable in and of themselves and are never ARARs. They may, however, constitute To-be-considered material (TBCs) 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.

8.2.4 New Source Performance Standards (NSPS)

Under the *NSPS* program, EPA establishes 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.

8.2.5 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% 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 be 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% by weight; organics from nonhazardous waste) (55 *FR* 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.

8.2.6 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 *FR* 8747–50):

- Interim measures,
- Equivalent standard of performance,
- Greater risk to health and the environment,
- Technical impracticability from an engineering perspective,
- Inconsistent application of state standards, and
- Fund balancing.

CERCLA § 121(d)(4)(F) restricts use of the fund-balancing waiver to remedial actions conducted under §104 of CERCLA and financed by the Superfund. This waiver is unavailable to ERPMs using funds obligated to DOE for their environmental restoration.

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 ROD signature, may indicate the possibility that an ARAR waiver may be invoked at a site (e.g., the RI/FS indicates it may be technically impracticable to attain MCLs in ground water). ERPMs should then consider including contingency language in the ROD.

8.3 Remediation Technologies

Typically, contaminants on Air Force installations consist of either organic solvents (e.g., perchloroethylene, trichloroethylene) or petroleum products (e.g., gasoline, 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 and may also include other criteria pollutants, HAPs, and GHGs, depending upon the contaminant in question. The contaminant involved at each remediation site (including any intermediate or final degradation products of the initial contaminant) must be known in order 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.**

The two most common technologies used in site remediation which result in air emissions 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 therefore 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 8-1.

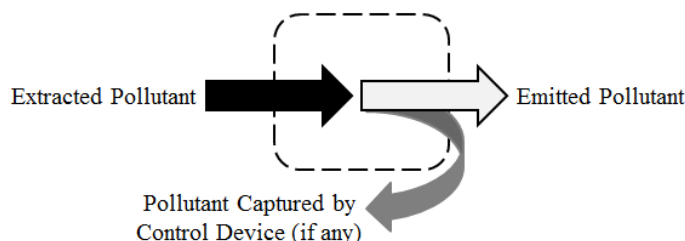


Figure 8-1. Simple Control Volume for Emissions from Site Remediation

8.3.1 Soil Vapor Extraction (SVE)

Soil vapor extraction (SVE) is a remediation technology that is used to remove VOCs from soil within the vadose (i.e. unsaturated) zone. This is accomplished using one or more extraction wells placed near the contaminant plume. These wells introduce a pressure gradient, resulting in air flow towards an extraction well. Any existing VOCs 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.

8.3.2 Air Stripping (AS)

Air stripping is often utilized concurrently with vacuum extraction 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.

8.4 NESHAP Applicability

National emission standards for hazardous air pollutants (NESHAPs) have been developed which apply to site remediation. 40 CFR 63 subpart GGGGG describes the standards required of any applicable facilities which perform site remediation. These standards are applicable to those facilities whose remediation site is co-located with one or more HAP emitting stationary sources that meet an affected source definition regulated by another subpart of 40 CFR 63, whose remediation site cleans up any material given in Table 1 of subpart GGGGG, and whose facilities are major sources of HAPs. This regulation states that any remediation of HAPs from leaking underground storage tanks at gasoline service stations are exempt from these standards. Consult this CFR to determine any possible exemptions which may apply or to verify that any remediation sites comply with these standards.

8.5 Emission Factors

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 which 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 Stationary Guide. However, emission factors for enclosed flares burning landfill gas may be used for this calculation and are presented here. Table 8-1 provides criteria pollutant emission factors while speciated HAP emission factors are given in Table 8-2.

Table 8-1. Criteria Pollutant Emission Factors for Landfill Gas Flares (Enclosed)

Fuel	Emission Factors (lb/10 ⁶ ft ³)						
	NO _x	CO	SO _x	VOC ¹	PM ₁₀	PM _{2.5} ⁽²⁾	GHG ³
Landfill Gas	40.0	1.5	7.3	2.7	10.0	10.0	55961.6

SOURCE: Air Pollution Control District County of San Diego. "Combustion – Gas Fuels." 1999. *County of San Diego*. Document. 21 October 2013.

1. Source document provided emission factor for ROG, which is assumed to be equal to VOC.
2. PM_{2.5} is assumed to be equal to PM₁₀ using PM_{2.5} fractions given by California Emission Inventory Development and Reporting System (CEIDARS).
3. GHG emission factors taken from tables C-1 and C-2 of 40 CFR 98 for landfill gas. They are presented in terms of equivalent CO₂ (CO₂e) by summing the product of the emission factors and the respective global warming potential (GWP) for each gas. The GWP for CO₂, CH₄, and N₂O are 1, 25, and 298 respectively.

Table 8-2. HAP Emission Factors for Landfill Gas Flares (Enclosed)

HAP	Emission Factors (lb/10 ⁶ ft ³)
	Landfill Gas
Acrylonitrile	1.74E-02
Benzene	7.80E-03
Carbon Disulfide	2.30E-03
Carbonyl Sulfide	1.50E-03
Chlorobenzene	1.50E-03
Chloroform	2.00E-04
Dichlorobenzene	---
Ethyl Benzene	2.54E-02
Ethylene Dichloride	2.10E-03
Formaldehyde	1.35E-01
Hexane	2.94E-02
Hydrogen Chloride	7.43E+00
Methyl Isobutyl Ketone	9.70E-03
Methylene Chloride	6.31E-02
Perchloroethylene	3.21E-02
Toluene	1.88E-01
1,1,1-Trichloroethane	3.30E-03
Trichloroethylene	1.92E-02
Vinyl Chloride	2.38E-02
Vinylidene Chloride	1.00E-03
Xylenes	6.67E-02

SOURCE: Air Pollution Control District County of San Diego. "Combustion – Gas Fuels." 1999. *County of San Diego*. Document. 21 October 2013.

8.6 Emissions Calculation

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. For site remediation, emissions are calculated depending upon the type of remediation technique being utilized. 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. Emissions from the two more common site 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 soil vapor extraction and air stripping are described below.

8.6.1 Soil Vapor Extraction (SVE)

In this case, 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 though the presence of atoms besides hydrogen and carbon reduce the detector's response. A PID contains an ultraviolet (UV) lamp which ionizes the incoming gas. The ions are driven to a collector electrode which 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 be capable of providing 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 soil vapor extraction 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. With the measured concentration of the pollutant (prior to the control device), the flow rate of the exhaust, and the time in operation during the year, the pollutant emissions from soil vapor extraction may be calculated as follows:

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

Equation 8-1

Where,

E_{Pol}	= Emissions of a particular 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-mol)
1.581x10⁻⁷	= Equation constant [(lb-mol 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:

$$\frac{1}{10^6 \text{ ppmv}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{1 \text{ lb-mol}}{379.5 \text{ ft}^3} = 1.581 \times 10^{-7} \left(\frac{\text{lb-mol} * \text{min}}{\text{ppmv} * \text{ft}^3 * \text{hr}} \right)$$

Emissions from each extraction well should be calculated individually and summed for the total emissions per chemical species. A detailed control volume of emissions from soil vapor extraction is provided in Figure 8-2.

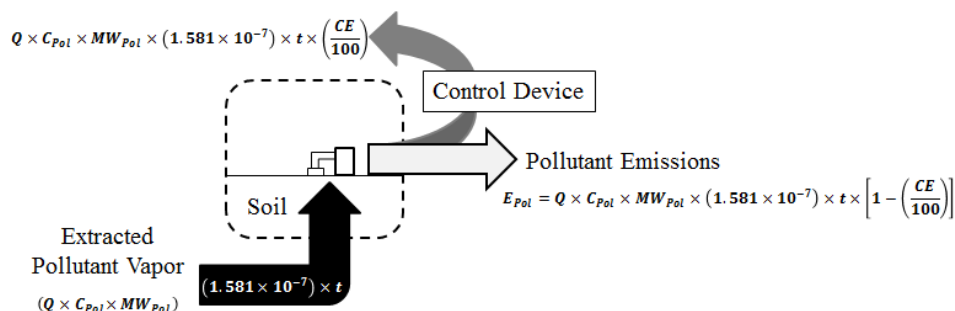


Figure 8-2. Soil Vapor Extraction Control Volume

8.6.2 Air Stripping (AS)

In order to calculate emissions from air strippers, the pollutant concentration in the groundwater must first be measured. Air emissions resulting from air strippers are calculated as follows:

$$E_{Pol} = Q \times C_{Pol} \times \left(\frac{RE}{100} \right) \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{CE}{100} \right) \right] \quad \text{Equation 8-2}$$

Where,

E_{Pol}	=	Emissions of a particular pollutant (lb/yr)
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 (%)
5.042x10⁻⁴	=	Equation constant [(lb L min)/(mg gal hr)]
t	=	Time in operation for the year (hr/yr)
CE	=	Control efficiency of the control device, if any (%)

The equation constant was derived as follows:

$$\frac{2.2 \text{ lb}}{10^6 \text{ mg}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{1000 \text{ L}}{261.8 \text{ gal}} = 5.042 \times 10^{-4} \left(\frac{\text{lb} \cdot \text{L} \cdot \text{min}}{\text{mg} \cdot \text{gal} \cdot \text{hr}} \right)$$

A detailed control volume of emissions from air stripping is provided in Figure 8-3.

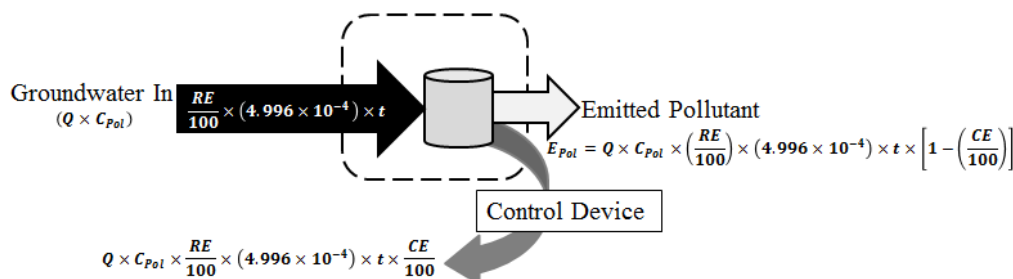


Figure 8-3. Air Stripping Control Volume

8.7 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 in order to obtain any required information.

8.8 Example Problems

Algorithms and emission factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. The only algorithms and EFs authorized for use in estimating Air Force emissions are those maintained within the Air Program Information Management System (APIMS).

8.8.1 Problem # 1 (Soil Vapor Extraction)

Anytown AFB is looking to calculate air emissions from a remediation site located on base. Soil Vapor Extraction (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 120ft³/min and an average measured PCE concentration of 215ppmv. 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 165.8lb/lb-mol, calculate the emissions of PCE from this process at this site.

Step 1 – Calculate emissions. All of the data required for emissions calculation is provided in the problem statement. Using this data and Equation 8-1, emissions may be calculated as follows:

$$E_{POL} = Q \times C_{POL} \times MW_{POL} \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

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

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

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

$$E_{PCE} = 4277640 \frac{ft^3 \ ppmv \ lb}{min \ lb-mol} \times (1.581 \times 10^{-7}) \frac{lb-mol \ min}{ft^3 ppmv \ hr} \times 1200 \frac{hr}{yr} \times [0.03]$$

$$E_{PCE} = 0.67629 \frac{lb}{hr} \times 1200 \frac{hr}{yr} \times [0.03]$$

$$E_{PCE} = 0.67629 \frac{lb}{hr} \times 1200 \frac{hr}{yr} \times [0.03]$$

$$E_{PCE} = 811.5539 \frac{lb}{yr} \times [0.03]$$

$$E_{PCE} = 24.3 \frac{lb}{yr}$$

8.8.2 Problem #2 (Air Stripping)

In addition to the emissions resulting from the SVE site on base, Anytown AFB 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 160mg/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. The problem statement provided all the data necessary for air emissions calculation. Using this data and Equation 8-2, VOC emissions are calculated as follows:

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

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

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

$$E_{Pol} = 7200 \frac{gal \cdot mg}{min \cdot L} \times (0.95) \times (5.042 \times 10^{-4}) \frac{lb \cdot L \cdot min}{mg \cdot gal \cdot hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$E_{Pol} = 6840 \frac{gal \cdot mg}{min \cdot L} \times (5.042 \times 10^{-4}) \frac{lb \cdot L \cdot min}{mg \cdot gal \cdot hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$E_{Pol} = 3.4487 \frac{lb}{hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$E_{Pol} = 3862.6 \frac{lb}{yr}$$

8.9 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.

9 WILDFIRES (WILD)

➤ Fugitive Source

9.1 Introduction

A wildfire is an uncontrolled fire that burns a variety of vegetation types ranging in age, size, and density. Consequently, wildfires are potential sources of large amounts of air pollution affecting air quality. Emissions from wildfires may travel large distances and contribute to the release of over 10 tons/km² of CO₂ annually in the United States (Liu, Stanturf and Tian). **Wildfires result in fugitive emissions of criteria pollutants and Greenhouse Gases (GHG).**

The size and intensity of a wildfire is affected by meteorological conditions, the species of vegetation involved and their moisture content, and the weight of consumable fuel per acre (fuel loading). The complete combustion of wildland fuels (forests, grasslands, and wetlands) requires a heat flux (temperature gradient), adequate oxygen supply, and sufficient burning time. The size and quantity of wildland fuels, meteorological conditions, and topographic features interact to modify the burning behavior as the fire spreads, and the wildfire will attain different degrees of combustion efficiency during its lifetime. A simple control volume describing emissions resulting from wildfires is provided in Figure 9-1.

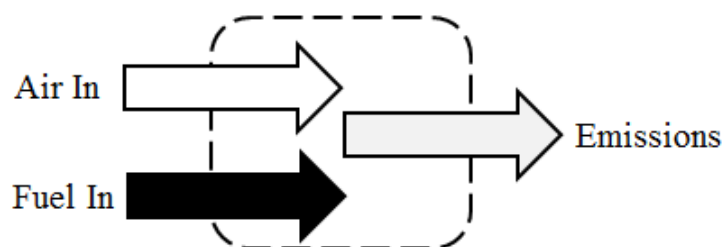
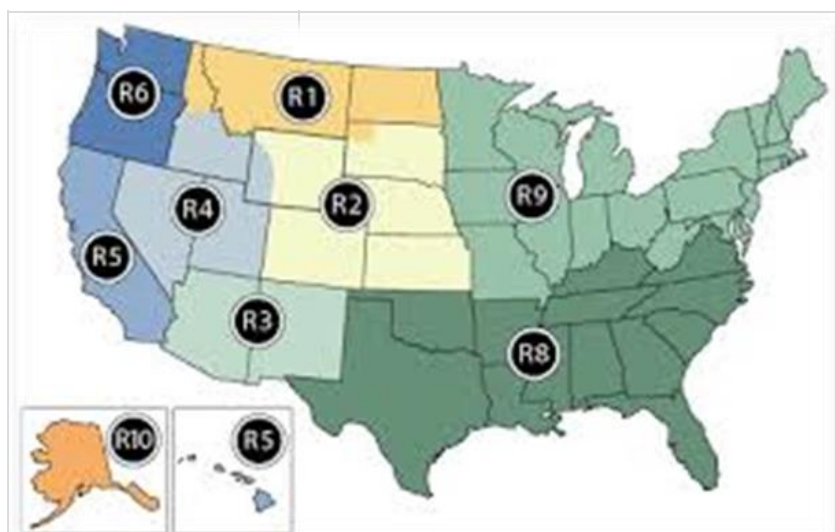


Figure 9-1. Simplified Wildfire Control Volume

Most fuel loading figures are based on values for "available fuel," that is, combustible material that will be consumed in a wildfire under specific weather conditions. Each region of the country will have varying fuel load due to landscape and vegetation type. The U.S. Forest Service Regions are shown in Table 9-1.

Table 9-1. Estimated Average Fuel Loading Factor

National Region	States
Rocky Mountain	AZ, CO, ID, KS, MT, ND, NE, NM, NV, SD, UT, WA, WY
Region 1: Northern	Northern ID, MT, ND, Northwestern SD, Northeast WA
Region 2: Rocky Mountain	CO, KS, NE, parts of SD, parts of WY
Region 3: Southwestern	AZ, NM
Region 4: Intermountain	Southern ID, NV, UT, Western WY
Pacific	AK, CA, HI, OR, WA
Region 5: Pacific Southwest	CA, HI
Region 6: Pacific Northwest	OR, WA
Region 10: Alaska	AK
Coastal	AK
Interior	AK
Southern	AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA
Region 8: Southern	AL, AR, FL, GA, KY, LA, MS, NC, OK, SC, TN, TX, VA
North Central	CT, DE, IA, IN, IL, MA, MD, ME, MI, MN, MO, NH, NJ, NY, OH, PA, RI, VT, WI, WV
Region 9: Conifers	CT, DE, IA, IN, IL, MA, MD, ME, MI, MN, MO, NH, NJ, NY, OH, PA, RI, VT, WI, WV
Hardwoods	CT, DE, IA, IN, IL, MA, MD, ME, MI, MN, MO, NH, NJ, NY, OH, PA, RI, VT, WI, WV

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

9.2 Emission Factors

The difficulty in establishing emission factors for use in estimating emissions from wildfires is that 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 meaning the vegetation species and moisture content may have the greatest impact on combustion intensity.

The United States Forest Service has developed nine regions across the United States (see Table 9-1) with their own set of criteria pollutant emission factors. These emission factors were developed for each region based on the expected vegetation and fuel loading factor. These emission factors are provided in Table 9-2.

Table 9-2. Criteria Pollutant Emission Factors for Wildfires

Geographic Area	Emission Factor (ton/acre)							
	NO _x	CO	SO _x	Pb	VOC	PM ₁₀ ⁽¹⁾	PM _{2.5} ⁽¹⁾	GHG ²
Rocky Mountain	7.41E-02	2.59E+00	---	---	4.44E-01	3.15E-01	3.15E-01	6.78E+01
Region 1: Northern	1.20E-01	4.20E+00	---	---	7.23E-01	5.10E-01	5.10E-01	1.10E+02
Region 2: Rocky Mountain	6.02E-02	2.10E+00	---	---	3.60E-01	2.55E-01	2.55E-01	5.49E+01
Region 3: Southwestern	2.01E-02	7.00E-01	---	---	1.20E-01	8.52E-02	8.52E-02	1.83E+01
Region 4: Intermountain	1.61E-02	5.62E-01	---	---	9.59E-02	6.83E-02	6.83E-02	1.47E+01
Pacific	3.79E-02	1.33E+00	---	---	2.28E-01	1.61E-01	1.61E-01	3.48E+01
Region 5: Pacific Southwest	3.61E-02	1.26E+00	---	---	2.16E-01	1.53E-01	1.53E-01	3.30E+01
Region 6: Pacific Northwest	1.20E-01	4.20E+00	---	---	7.23E-01	5.10E-01	5.10E-01	1.10E+02
Region 10: Alaska	3.21E-02	1.12E+00	---	---	1.92E-01	1.36E-01	1.36E-01	2.93E+01
Southern	1.78E-02	6.29E-01	---	---	1.08E-01	7.67E-02	7.67E-02	1.65E+01
Region 8: Southern	1.78E-02	6.29E-01	---	---	1.08E-01	7.67E-02	7.67E-02	1.65E+01
North Central	2.19E-02	7.72E-01	---	---	1.32E-01	9.37E-02	9.37E-02	2.01E+01
Region 9	2.19E-02	7.72E-01	---	---	1.32E-01	9.37E-02	9.37E-02	2.01E+01

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

1. Source document provides emission factor for total PM. The total PM conservatively assumed to be equal to PM₁₀ and PM_{2.5}
2. GHG emission factors are the sum of the product of CO₂, CH₄, and N₂O and their respective global warming potentials (GWP). The GWP potentials and emission factors were taken from 40 CFR 98 Tables C-1 and C-2 and assume the fuel is composed of wood and wood residuals. The estimated fuel loading factors for each region as given in Table 13.1-1 of AP-42 were used in the calculation of the emission factors.

“---” – Indicates No Data Available

9.3 Emissions Calculation

Algorithms and Emission Factors (EFs) used by the Air Force are generally from AP-42; however, EFs for Air Force-unique sources have been developed by the Air Force. Emissions from wildfires are calculated by multiplying the emission factor by the estimated area of land burned:

$$E_{Pol} = A \times EF_{Pol}$$

Equation 9-1

Where,

- E_{Pol}** = Annual emissions of pollutant (ton/yr)
A = Area of land burned (Acres)
EF_{Pol} = Emission factor (ton/acre)

A detailed control volume describing the calculation of emissions from wildfires is given in Figure 9-2.

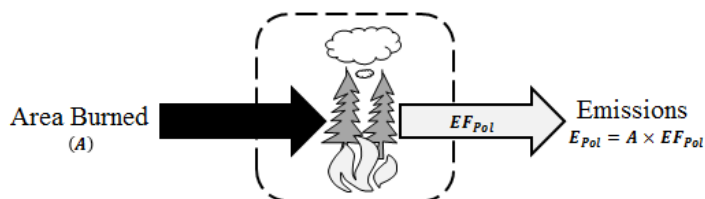


Figure 9-2. Wildfire Control Volume

9.4 Information Resources

As more data becomes available and emissions models from wildfires become more accurate, it may be beneficial to utilize these models (such as FOFEM, EES, etc.) in making emissions estimations. In the meantime, information needed for emissions calculations, such as area burned or even vegetation speciation, may be available from either a state or local forestry agency or the U.S. Forest Service. Contact these agencies for this data or additional guidance as necessary.

9.5 Example Problem

A Utah AFB experienced a wildfire that consumed 18 acres of land. Calculate the carbon monoxide (CO) and PM₁₀ emissions produced from the fire.

Step 1 – Determine the region the AFB lies within. The problem stated that the AFB is located in Utah. According to Table 9-1, the AFB is located in **Region 4**.

Step 2 – Select and record emission factors. According to Table 9-2, the CO and PM₁₀ emission factors in region 4 are **5.62E-01** and **6.83E-02 ton/acre** respectively.

Step 3 – Calculate emissions. Using the emission factors recorded in Step 2, the total area burned as provided in the problem statement, and Equation 9-1, the CO and PM₁₀ emissions are calculated as follows:

$$E_{Pol} = A \times EF_{Pol}$$

For CO:

$$E_{CO} = 18 \frac{\text{Acre}}{\text{yr}} \times 0.562 \frac{\text{ton}}{\text{Acre}}$$

$$E_{CO} = 10.12 \frac{ton}{yr}$$

For PM₁₀:

$$E_{PM_{10}} = 18 \frac{Acre}{yr} \times 0.0683 \frac{ton}{Acre}$$

$$E_{PM_{10}} = 1.23 \frac{ton}{yr}$$

9.6 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

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USEPA 1996, 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