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

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## ACRONYMS

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

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

| MIDAS | Munitions Items Disposition Action System |
| NAAQS | National Ambient Air Quality Standards |
| NAICS | North American Industry Classification System |
| NASA | National Aeronautics and Space Administration |
| NEPA | National Environmental Policy Act |
| NESHAP | National Emission Standards for Hazardous Air Pollutants |
| NEW | Net Explosive Weight |
| OCONUS | Outside Continental United States |
| OTAQ | Office of Transportation and Air Quality |
| PEMS | Predictive Emission Monitoring System |
| RCRA | Resource Conservation and Recovery Act |
| SAR | Second Assessment Report |
| SAW | Submerged Arc Welding |
| SIC | Standard Industrial Classification |
| SIP | State Implementation Plan |
| SMAW | Shielded Metal Arc Welding |
| SME | Subject Matter Expert |
| STAPPA | State and Territorial Air Pollution Program Administrators |
| TIM | Time in Mode |
| 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 |
| AERR | Air Emissions Reporting Requirements |
| AFB | Air Force Base |
| AFI | Air Force Instruction |
| AFPMB | Armed Forces Post Management Board |
| AFRL | Air Force Research Laboratory |
| APU | Auxiliary Power Unit |
| BFB | Bubbling Fluidized Bed |
| BMP | Best Management Practices |
| BSFC | Brake-Specific Fuel Consumption |
| CAA | Clean Air Act |
| CAAA | Clean Air Act Amendments (of 1990) |
| CE | Civil Engineering |
| CEMS | Continuous Emission Monitoring System |
| CEV | Civil Engineering Environmental |
| CFB | Circulating Fluidized Bed |
| CFC | Chlorofluorocarbon |
| CFR | Code of Federal Regulations |
| CI | Compression Ignition |
| CNG | Compressed Natural Gas |
| DLA | Defense Logistics Agency |
| DoD | Department of Defense |
| DOE | Department of Energy |
| EA | Environmental Assessment |
| EDMS | Emissions and Dispersion Modeling System |
| EF | Emission Factor |
| EGBE | Ethylene Glycol Butyl Ether |
| EIIP | Emissions Inventory Improvement Program |
| EIP | Emissions Inventory Plan |
| EIR | Emissions Inventory Report |
| EIS | Environmental Impact Statement |
| EOD | Explosive Ordnance Disposal |
| EPA | Environmental Protection Agency |
| ERP | Environmental Restoration Program |
| ESP | Electrostatic Precipitator |

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

| | |
|---|---|
| MPF | Military Personnel Flight |
| MPO | Metropolitan Planning Office |
| MSDS | Material Safety Data Sheet |
| MSW | Municipal Solid Waste |
| NACAA | National Association of Clean Air Agencies |
| NC | Nameplate Capacity |
| NDI | Non-destructive Inspection |
| NEI | National Emission Inventory |
| NMHC | Non-Methane Hydrocarbons |
| NMOC | Non-Methane Organic Compounds |
| NMTOC | Non-Methane Total Organic Compounds |
| NSCR | Nonselective Catalytic Reduction |
| NSPS | New Source Performance Standards |
| NSR | New Source Review |
| OBOD | Open Burning/Open Detonation |
| OBODM | Open Burning/Open Detonation Model |
| OCA | Off-Site Consequences Analysis |
| ODC | Ozone Depleting Chemicals |
| ODP | Ozone Depletion Potential |
| ODS | Ozone Depleting Substances |
| OIAI | Once In Always In |
| OLVIMS | On-line Vehicle Interactive Management System |
| P2 | Pollution Prevention |
| PAH | Polycyclic Aromatic Hydrocarbon |
| PBT | Persistent Bioaccumulative and Toxic |
| PM | Particulate Matter – Aerodynamic diameter unspecified |
| PM10 | Particulate Matter – Aerodynamic diameter < 10 micrometers |
| PM2.5 | Particulate Matter – Aerodynamic diameter < 2.5 micrometers |
| POL | Petroleum, Oil, and Lubricant |
| POTW | Publicly Owned Treatment Works |
| POV | Privately Owned Vehicles |
| PSD | Prevention of Significant Deterioration |
| PTE | Potential to Emit |
| RMP | Risk Management Plan |
| RVP | Reid Vapor Pressure |
| SCC | Source Classification Code |
| SDS | Safety Data Sheets |
| SCR | Selective Catalytic Reduction |
| SF | Spillage Factor |
| SI | Spark Ignition |

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

## ABBREVIATIONS

(Shortened form of a word or phrase)

| | |
|---|---|
| μg | Microgram(s) |
| A-hr | Ampere-hours |
| A/ft2 | Ampere per square foot |
| Btu | British Thermal Unit |
| ºC | Degrees Celsius |
| CH4 | Methane |
| CO | Carbon Monoxide |
| CO2 | Carbon Dioxide |
| Co | Cobalt |
| Cr | Chromium |
| Cr+6 | Hexavalent Chromium |
| Cr2O3 | Chromium Oxide |
| EtO | Ethylene Oxide |
| ºF | Degrees Fahrenheit |
| ft | Foot (Feet) |
| g | Grams |
| g/L | Grams per Liter |
| gal | Gallon(s) |
| HCl | Hydrochloric Acid |
| hp | Horse Power |
| hr | Hour(s) |
| kg | Kilogram |
| kW | Kilowatt(s) |
| L | Liter |
| lb | Pound(s) |
| Mg | Megagram(s) [i.e., metric ton] |
| mg | Milligram(s) |
| MMBtu | Million British Thermal Units |
| Mn | Manganese |
| NH3 | Ammonia |
| Ni | Nickel |
| N2O | Nitrous Oxide |
| NO2 | Nitrogen Dioxide |
| NOX | Nitrogen Oxides |
| O3 | Ozone |
| Pb | Lead |
| PERC | Perchloroethylene |

| | |
|---|---|
| PFC | Perfluorocarbon |
| ppm | Parts per Million |
| ppmv | Parts per Million by Volume |
| ppmw | Parts per Million by Weight |
| psi | Pounds per Square Inch |
| psia | Pounds per Square Inch Absolute |
| ºR | Degrees Rankin |
| scf | Standard Cubic Foot |
| SF6 | Sulfur Hexafluoride |
| SO2 | Sulfur Dioxide |
| SOX | Sulfur Oxides |
| TNT | Trinitrotoluene |
| tpy | Tons per Year |
| yr | Year(s) |

## 1.0   INTRODUCTION

### 1.1   Background and Purpose

To better control hazardous air emissions and reduce them, the Clean Air Act (CAA) was established in 1970 as a Federal law to reduce emissions of harmful pollutants.  The United States 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) that require facility managers to always know if they comply 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 included in stationary and mobile AEIs.  However, transitory sources should not normally be included in a stationary or mobile AEI unless the source becomes fixed and/or routinely operated (i.e., year-round emitter)**.

This document covers transitory sources and their emissions that may be located on an Air Force Installation.  Any questions concerning this document, calculation methodologies for sources not provided here, or requests for additional information pertaining to Air Force AEIs should be directed to the Air Quality Subject Matter Expert, Air Force Civil Engineer Center (AFCEC), Compliance Technical Support Branch, 250 Donald Goodrich Drive, Building #1650, San Antonio, TX 78226.

### 1.2   Transitory Sources

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

Transitory sources are <u>non-routine</u> and/or <u>seasonal sources</u> (may be stationary, mobile or neither) that are short-term in nature.  Historically, transitory sources have been erroneously included as stationary or mobile sources in AEIs.  Transitory source emissions should generally only be

accounted for in evaluating potential air quality impacts of proposed actions under the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), National Environmental Policy Act (NEPA), and General Conformity.

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

- **Point Sources** – not naturally occurring, discrete sources of emissions which emit through a stack, chimney, vent, or other functionally equivalent opening.  Examples include stationary engines, boilers, and paint booths.

- **Fugitive Sources** – not naturally occurring sources of emissions which could not reasonably pass through a stack, chimney, vent or other functionally equivalent opening.  Examples include open burns, firefighter training, and pesticide application.

- **Biogenic Sources** – naturally occurring sources of emissions.  Examples include emissions from soil and vegetation, lightning, and volcanic emissions.

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

### 1.2.1   Non-routine Sources

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

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

### 1.2.2   Seasonal Sources

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

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

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

## 1.3    Pollutants

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

### 1.3.1    Criteria Pollutants

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

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

- PM includes the very fine dust, soot, smoke, and droplets formed from chemical reactions and incomplete burning of fuels.

- The fine particles of PM can get deep into the lungs, causing increased respiratory illnesses and tens of thousands of deaths each year.

- PM is defined as any particle with an equivalent diameter of less than or equal to 10 microns (**$PM_{10}$**) and is further subdivided to include a separate standard for particles with an equivalent aerodynamic diameter of less than or equal to 2.5 microns (**$PM_{2.5}$**).

**Ground-Level Ozone (O₃):**

- O₃ is a primary component of smog that causes human health problems and damage to forests and agricultural crops.

- Repeated exposure to O₃ can make people more susceptible to respiratory infections and lung inflammation.

- Though there is a NAAQS, **O₃ is not emitted directly into the air.**

- Two types of compounds that are the main ingredients (precursors) in forming ground-level O₃ in the presence of ultraviolet (UV) light include:
  - **Volatile Organic Compounds (VOCs):** Defined as "any compound of carbon, excluding carbon monoxide (CO), carbon dioxide ($CO_2$), carbonic acid, metallic carbides or carbonates, and ammonium carbonate, which participates in atmospheric photochemical reactions" (40 CFR 51.100). Note that 40 CFR 51.100 also exempts compounds based on their negligible photochemical reactivity. Examples of these exempt compounds include methane, ethane, acetone, et al. Common sources of VOCs include gas and diesel-fueled automobiles, fuel storage containers, and solvents used in paints and degreasers.
  - **Nitrogen oxides ($NO_X$):** Provides the reddish-brown tint in smog. These are produced from the burning of gasoline, coal, or oil.

**Carbon Monoxide (CO):**

- CO is produced when fossil fuel burns incompletely because of insufficient oxygen ($O_2$).

- Wood, coal, and charcoal fires and gasoline engines always produce CO.

- In the United States, particularly in urban areas, most CO air emissions are from mobile sources.

- CO can cause harmful health effects by reducing $O_2$ delivery to the body's organs (like the heart and brain) and tissues.

**Sulfur Dioxide ($SO_2$):**

- $SO_2$ is a subset of highly reactive gases known as "oxides of sulfur." Since $SO_2$ is the most common of the sulfur oxides, it is used to represent $SO_X$ emissions.

- $SO_2$ in the ambient air is just one of several oxides of sulfur that contribute to air quality issues.

- $SO_2$ emissions are produced from fossil fuel combustion at power plants (73 percent) and other industrial facilities (20 percent).

- $SO_2$ is linked to several adverse effects on the respiratory system.

**Nitrogen Dioxide (NO$_2$):**

- NO$_2$ is a subgroup of nitrogen oxides and is the most environmentally concerning component. It also acts as an indicator for the presence of the larger group of NO$_X$.

- NO$_2$ forms quickly from vehicle, power plant, and off-road equipment emissions.

- NO$_2$ contributes to the formation of ground-level O$_3$ and fine particle pollution.

- NO$_2$ is linked to several adverse effects on the respiratory system.

**Lead (Pb):**

- Pb is a metal found naturally in the environment as well as in manufactured products.

- Prior to 1980, the major sources of Pb were on-road vehicles. As a result, the EPA removed Pb from motor vehicle gasoline, resulting in a 95% decline in Pb emissions between 1980 and 1999.

- Today, the major sources of Pb are ore and metals processing (e.g., lead smelters).

- Depending on the level of exposure, Pb can adversely affect the nervous system, kidney function, immune system, reproductive and developmental systems and the cardiovascular system.

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

Also, note that O$_3$ is not directly emitted into the air, but is created through photochemical reactions involving NO$_X$ and VOCs, and PM may be the result of the release of primary pollutants or the formation of secondary pollutants. Therefore, this Guide provides EFs for a list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of "criteria pollutants" for emissions inventory purposes are reported as those shown below:

- CO
- NO$_X$
- PM$_{10}$
- PM$_{2.5}$
- SO$_X$
- VOCs
- Pb

### 1.3.2   Hazardous Air Pollutants (HAPs)

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

### 1.3.3   Greenhouse Gases (GHGs)

Global climate change is becoming one of the most important issues of the 21st century. Some GHGs, such as $CO_2$, are emitted to the atmosphere through both naturally occurring processes as well as human activities. Other GHGs (e.g., fluorinated gases) are created and emitted solely through human activities. The principal GHGs emitted to the atmosphere through human actions are $CO_2$, methane ($CH_4$), nitrous oxide ($N_2O$), and fluorinated gases.

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

GHGs are assigned a Global Warming Potential (GWP), which is a measure of how much heat the gas traps in the atmosphere calculated over a specific time interval, typically 100 years. The higher the GWP, the greater the potential for the gas to trap heat, and the more harmful the gas is regarded. $CO_2$ is used as the baseline gas and assigned a GWP of 1. GHG emissions are converted into equivalent $CO_2$ ($CO_2e$) by taking the product of the emissions of each GHG and its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several GHGs. The GWP values given throughout this Guide are subject to change in the upcoming years due to new data becoming available but are considered current as of June 2020. The total GHG emissions are calculated by summing all emissions from each gas and is generally derived from the following equation:

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

**Equation 1-1**

Where,

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

## 1.4   Applicable Air Quality Related Regulations

### 1.4.1   CAA Titles

Title I of the CAA requires each State to develop a State Implementation Plan (SIP), which identifies sources of air pollution and the plans for reducing emissions to meet the Federal air quality standards.  Under Title I of the CAA, the EPA is also tasked with establishing and enforcing New Source Performance Standards (NSPS) and National Emission Standards for Hazardous Air Pollutants (NESHAP), which are aimed at reducing emissions from new stationary sources and controlling emissions of 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 CAA known as Clean Air Act Amendment of 1990 (CAAA-90).  Title III of CAAA-90 further directed the EPA to develop a list of sources that emit HAPs and establish regulations for each source category. Major sources and area sources for HAPs are required to abide by the "Maximum Achievable Control Technology" (MACT) standards issued by the EPA that has a prescribed schedule. Under Title V of the CAAA-90, those stationary sources that are considered a "major source" must obtain a Title V operating permit.  A major source under Title V includes any stationary source or group of stationary sources within a contiguous or adjacent properties and under common control that emits or has the potential to emit:

- 10 tpy or more of any HAP **or** 25 tpy or more of any combination of HAPs.

- 100 tpy or more of any air pollutant subject to regulation.  For some of the criteria pollutants, lower thresholds exist for certain nonattainment areas including:
  - 50 tpy of VOC and $NO_X$ emissions in "serious" $O_3$ nonattainment areas and in $O_3$ transport regions.
  - 25 tpy of VOC and $NO_X$ emissions in "severe" $O_3$ nonattainment areas.
  - 10 tpy of VOC and $NO_X$ emissions in "extreme" $O_3$ nonattainment areas.
  - 50 tpy of CO emissions in "serious" CO nonattainment areas.
  - 70 tpy of $PM_{10}$ emissions in "serious" $PM_{10}$ nonattainment areas.

### 1.4.1.1   New Source Review (NSR)

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

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

Nonattainment NSR permits are required for new major sources or major modifications at existing sources located in nonattainment areas.  All nonattainment NSR programs require the installation of the Lowest Achievable Emission Rate (LAER).  LAER is determined either by taking the most stringent emission limitation contained in a SIP for the category source or the most stringent emission limit achieved in practice by such class or category of source, whichever is more constraining.  Additionally, since the construction is to take place in a nonattainment area, part of the nonattainment NSR program requires some form of emission offsets.  These offsets are reductions in emissions from existing sources near the proposed construction that 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 that does not require PSD or nonattainment NSR permits.  These permits contain requirements limiting the emissions to avoid PSD and nonattainment NSR, and to prevent the new construction from violating the control strategy in a nonattainment area.

**1.4.1.2   General Conformity**

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

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

**1.4.2   National Environmental Policy Act (NEPA)**

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

- **Categorical Exclusion Determination** – A Categorical Exclusion Determination is a proposed action that may be categorically excluded from a detailed environmental analysis if the action meets certain criteria that a previous agency has previously determined to have no significant environmental impact.

- **Environmental Assessment (EA)** – An Environmental Assessment is a proposed action not categorically excluded and must be evaluated to determine if its undertaking would significantly affect the environment.  If there is no significant affect, the agency issues a Finding of No Significant Impact (FONSI).  If the EA concludes the action results in a significant environmental impact, an Environmental Impact Statement must be prepared.

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

### 1.4.3   Environmental Impact Analysis Process (EIAP)

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

## 1.5   Authoritative Algorithms and Emission Factors (EFs)

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

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

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

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


## 1.6   Emissions Inventory Methodologies

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

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

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

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

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

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

**Equation 1-2**

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

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

## 1.7   Guide Organization

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

## 1.8   References

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

40 CFR 51, "Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency, Subchapter C-Air Programs, Part 51-Requirements for Preparation, Adoption, 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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## 2.0    BULK STORAGE TANK CLEANING (TCRL)

➢ *Fuguitive* Source

### 2.1   Introduction

Storage tanks located on Air Force installations are used for storing materials, which commonly include fuels such as JP-8, Jet A, MOGAS, and diesel, or even asphalt 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 EPA, an underground storage tank (UST) is defined as a tank and any underground piping system that has 10% or more of its combined volume underground.  Liquid storage tanks that have more than 90% of their volume above the ground surface are classified as above ground storage tanks (AST).  Various types of tanks can be used for storage, but the most common types found on an AF installation are tanks with a roof that are either self-supporting fixed roof or external floating roof types.  Other tanks with roofs include internal floating roof and column-supported fixed roof tanks.

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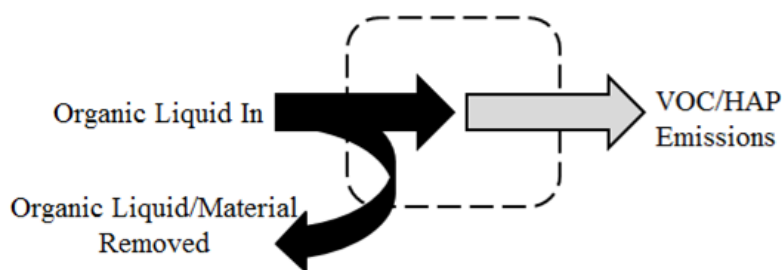


**Figure 2-1. Simplified Bulk Storage Tank Cleaning Control Volume**

There are several types of roof designs for storage tanks that influence the amount of emissions released from tank use, though have no effect on the amount of emissions released during tank

cleaning.  For more data on storage tanks and their emissions, refer to the "Storage Tanks" chapter of the latest version of the *Air Emissions Guide for Air Force Stationary Sources* 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 re-tested and chemical corrections are made, as needed

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

## 2.2   NESHAP Applicability

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

## 2.3   Control Techniques

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


## 2.4   Emissions Calculation

Emissions from bulk tank cleaning operations occur from tank degassing and the evaporation of VOCs in the sludge.  Note that there are different processes and types of equipment used in cleaning storage tanks therefore, emissions 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.

This chapter outlines the process for estimating emissions from tank cleanings and the landings of floating roof tanks during tank turnovers.  The total emissions for these processes are calculated by estimating the emissions for each event multiplied by the number of events per year for each tank:

$$E(Pol) = \sum_{i=1}^{n}[E(Pol)_i \times N_i]$$

**Equation 2-1**

Where,

$E(Pol)$ = Total annual emissions of pollutant (lb/yr)

$E(Pol)_i$ = Pollutant emissions per event - bulk storage tank cleaning or roof landing (lb/cleaning)

$N_i$ = Number of events – cleaning or roof landing- for each tank per year (cleanings/yr)

$i$ = Tank identifier


### 2.4.1   Emissions from Tank Cleanings

The EPA recommends that emissions from bulk storage tank cleaning is approximated from two processes.  The first process is the emptying or degassing of the storage tank based on tank type (fixed roof vs. floating roof).  The second process is the cleaning or sludge handling using a conservative approach by assuming the sludge is 80% liquid, therefore the remainder 20% is emitted VOCs.

**Emptying (degassing)**

1.  For a fixed roof tank, calculate emissions from one turnover with the turnover factor (Kn) = 1 to account for vapors displaced during filling and then add the emissions from 1 turnover calculated as if the tank had a floating roof to account for clingage.
2.  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 (about 6 or 7 ft.) to approximate the vapor displaced from the space under the floating roof.

**Cleaning (sludge handling)**

Most wet sludges are about 80% to 90% liquid by weight.  A conservative approach for estimating emissions is to assume the sludge is 80% liquid.  The remainder is assumed to be VOC and emitted.  As an alternative, the actual sludge moisture content can be determined (EPA 2016).

Using the procedure recommended by the EPA, the vapor losses from tank cleaning include:

*   Withdrawal loss (clingage),
*   Sludge handling loss, and
*   Working loss (displaced vapors during filling)

Note that this procedure does not include the tank emptying prior to cleaning, since the product within the tank may be quickly emptied which would create a negative pressure and cause air to be drawn into the tank rather than allow vapor emissions to escape.  The assumption is that there are no emissions during this step.

The pollutant emissions from one bulk storage tank cleaning occurrence are calculated as follows:

$$E(Pol) = (L_{WD} + L_{SH} + L_W) \times \frac{WP(Pol)}{100}$$

**Equation 2-2**

Where,

| | | |
|---|---|---|
| $L_{WD}$ | = | Withdrawal/clingage loss per bulk storage tank cleaning (lb/cleaning) |
| $L_{SH}$ | = | Sludge handling loss per bulk storage tank cleaning (lb/cleaning) |
| $L_W$ | = | Working loss per bulk storage tank cleaning (lb/cleaning) |
| **WP(Pol)** | = | Weight percent pollutant in vapor (%) |
| **100** | = | Factor converting percent to a fraction |

### 2.4.1.1 Withdrawal Loss (Clingage)

Withdrawal losses result from the evaporation of wetted surfaces, known as clingage, after the product has been drained from the tank. Clingage emissions are calculated using the emission estimation procedures for withdrawal losses within Chapter 7 of EPA's *Compilation of Air Pollutant Emission Factors* (AP-42). The clingage/withdrawal loss is 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 based on material stored.

Given that a self-supported fixed-roof tank is the least expensive and considered the minimum acceptable equipment, the assumption is that most on-base roof tanks are either self-supporting fixed roof or external floating roof types. Under this assumption, clingage/withdrawal loss is calculated as follows:

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

**Equation 2-3**

Where,

| | | |
|---|---|---|
| **0.132** | = | Equation constant ($10^3$ft$^3$ gal/ft$^2$ bbl) |
| **D** | = | Tank diameter (ft) |
| **h** | = | Tank height (ft) |
| **Cs** | = | Clingage factor (bbl/$10^3$ ft$^3$ cleaning). **Use 0.0015 for single component stock.** |
| **W$_L$** | = | Average liquid density (lb/gal) |

Equation 2-3 was derived from Equation 2-4 from Section 7.1.3.2.1 in AP-42 with the assumption that the tank has either a self-supporting fixed roof or external floating roof and one turnover. The equation was modified to account for the circular sides of a cylindrical tank shell.

For internal floating roof and column-supported fixed roof tanks, use the tank-specific data and Equation 2-4 from Section 7.1.3.2.1 of AP-42 instead of Equation 2-3 from this Guide to calculate the withdrawal/clingage loss.

### 2.4.1.2 Sludge Handling Loss

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. Losses attributed to sludge handling are estimated as follows:

$$L_{SH} = M_S \times \left[1 - \left(\frac{MC}{100}\right)\right]$$

**Equation 2-4**

Where,

$M_S$ = Mass of the sludge removed (lb/cleaning)

MC = Moisture content of the sludge (%). **Use 80% if unknown/conservative.**

100 = Factor converting percent to a fraction (%)

The EPA states that sludge is typically 80% to 90% liquid by weight (USEPA 2016). A conservative approach is to assume that 80% is liquid and the remaining 20% is solid VOCs that are emitted. Alternatively, the sludge moisture content may be measured directly and used in this calculation.

Some storage tank cleaning operations may require the use of solvents to break up the sludge remaining in the tank. A common solvent used is high pressured water that is heated, and/or a commercial degreasing solution composed of VOCs and/or HAPs. Most operations that use solvents for sludge removal have a delivery and vacuum system that actively measures the mass of solvent added and removed. Since any solvents applied during tank cleaning are removed via a vacuum system with vapor control, the contribution of pollutant emissions from the application of these solvents are regarded as negligible and not calculated in this Guide.

The mass of the sludge ($M_S$) 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:

$$M_S = D \times V_S = SG \times 62.3 \times V_S$$

**Equation 2-5**

Where,

D = Density of sludge (lb/ft$^3$)

$V_S$ = Volume of the sludge (ft$^3$)

SG = Sludge specific gravity. Use a value of 1 if unknown.

62.3 = Density of water at 70°F (lb/ft$^3$)

The configuration of the tank (i.e., horizontal vs vertical) determines the calculation method 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.  The volume in both a vertical and horizontal cylindrical tank is calculated using the appropriate equations below:

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

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

Where,

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

### 2.4.1.3  Working Loss

Emissions from working losses during tank cleanings are estimated using the tank dimensions, and the properties of the organic liquid as shown:

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

**Equation 2-6**

Where,

| | | |
|---|---|---|
| **0.00014** | = | Equation constant (lb-mol/psia ft$^3$ cleaning) |
| **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) |

A detailed control volume for emissions resulting from tank cleaning is provided in Figure 2-2.
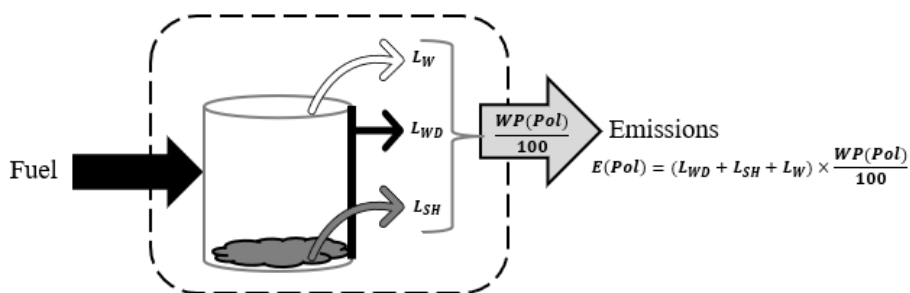


**Figure 2-2.  Bulk Storage Tank Cleaning Control Volume**

### 2.4.2  Emissions from Landing a Floating Roof

Emissions estimates for tanks with a floating roof during a tank turnover are a special case.  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.  The emissions from each landing is calculated as follows:

$$E(Pol) = (L_{SL} + L_{FL}) \times \frac{WP(Pol)}{100}$$

**Equation 2-7**

Where,

$L_{SL}$  =  Standing idle loss during roof landing (lb/landing episode)
$L_{FL}$  =  Filling loss after roof landing (lb/landing episode)

### 2.4.2.1   Standing Idle Loss

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.  When the roof is landed, vapor may continue to be emitted into the atmosphere through the vent, resulting in standing idle losses.  Standing idle loss is 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 ($ft^3$)
$R$  =  Ideal gas constant, 10.731 (psia-$ft^3$/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 from AP-42.  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 Equation 2-16 of Section 7.1.3.2.2 of AP-42 simplifies to Equation 2-8 above.

### 2.4.2.2   Filling Loss

The filling loss is the result of emissions as the tank is refilled, and the liquid reaches the level of the floating roof.  This value is calculated 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 for a partial heel

A detailed control volume for tank landings is provided in Figure 2-3.
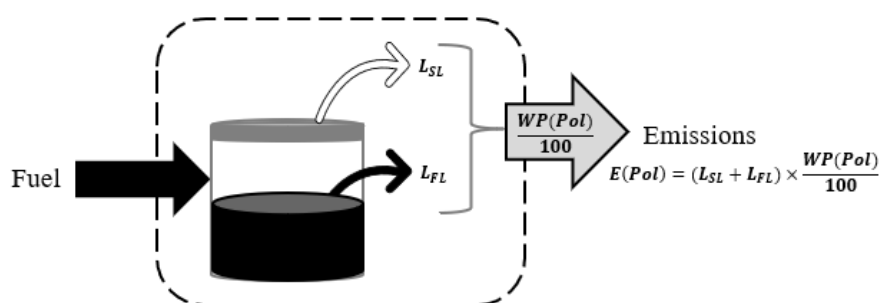


**Figure 2-3.  Control Volume for Floating Roof Landings**

## 2.5   Information Resources

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

## 2.6   Example Problem

A USAF Base 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 height of 20 feet.  Approximately 3 inches of sludge is estimated to be caked on the tank floor.  Calculate the total HAP emissions from the cleaning of this tank.  (Assume the diesel density, vapor molecular weight, and vapor pressure, are 7.14 lb/gal, 130 lb/lb-mol, and 0.009 psia, respectively.  Also, assume total HAP weight percent in liquid and vapor phase are 0.79% and 10.3% respectively.)

**Step 1 – Calculate the withdrawal/clingage loss.** Using the data from the problem statement and Equation 2-3, the clingage loss is calculated as follows:

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

$$L_{WD} = 0.132 \frac{10^3 ft^3 \, gal}{ft^2 \, bbl} \times 40ft \times \left(20ft + \frac{40ft}{2}\right) \times 0.0015 \frac{bbl}{10^3 ft^3} \times 7.14 \frac{lb}{gal}$$

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

$$\boldsymbol{L_{WD}} = 0.132 \frac{10^3 ft^3 \, gal}{ft^2 \, bbl} \times 1600 ft^2 \times 0.0015 \frac{bbl}{10^3 ft^3} \times 7.14 \frac{lb}{gal} = \boldsymbol{2.26 \, lb}$$

**Step 2 – Calculate the volume of the sludge.** The problem stated that the tank is vertical and the sludge was approximately 3 inches thick. The volume of the sludge is estimated as follows:

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

$$V_S = \pi \times \frac{(40ft)^2}{4} \times 3in \times \frac{1 \, ft}{12 \, in}$$

$$\boldsymbol{V_S} = \pi \times 400 ft^2 \times 0.25 ft = \boldsymbol{314.16 \, ft^3}$$

**Step 3 – Calculate the mass of the sludge remaining in the tank.** 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 2, and Equation 2-5, the mass of the sludge is calculated as follows:

$$M_S = SG \times 62.3 \times V_S$$

$$\boldsymbol{M_S} = 1 \times 62.3 \frac{lb}{ft^3} \times 314.16 \, ft^3 = \boldsymbol{19,572.17 \, lb}$$

**Step 4 – Calculate the sludge handling loss.** The moisture content of the sludge was not given, therefore a conservative estimate of 80% may be used. The sludge handling loss is estimated using Equation 2-4 as shown:

$$L_{SH} = M_S \times \left[1 - \left(\frac{MC}{100}\right)\right]$$

$$L_{SH} = 19,572.17 \, lb \times \left[1 - \left(\frac{80\%}{100\%}\right)\right]$$

$$\boldsymbol{L_{SH}} = 19,572.17 \, lb \times [0.2] = \boldsymbol{3,914.43 \, lb}$$

**Step 5 - Calculate the filling loss.** Using the data from the problem statement and Equation 2-6, the filling loss is calculated as follows:

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

$$L_W = 0.00014 \frac{lb-mol}{psia\ ft^3} \times 130 \frac{lb}{lb-mol} \times 0.009\ psia \times ([40ft]^2 \times 20ft)$$

$$\boldsymbol{L_W} = 0.00014 \frac{\cancel{lb-mol}}{\cancel{psia\ ft^3}} \times 130 \frac{lb}{\cancel{lb-mol}} \times 0.009\ \cancel{psia} \times (32000\cancel{ft^3}) = \boldsymbol{5.24\ lb}$$

**Step 6 – Calculate the total HAP emissions from this cleaning.** Using the weight percent of HAPs in the liquid phase as given in the problem statement (0.79%), the clingage/withdrawal loss, sludge handling loss, filling loss, and Equation 2-2, the HAPs are calculated as follows:

$$E(Pol) = (L_{WD} + L_{SH} + L_W) \times \frac{WP(Pol)}{100}$$

$$E(HAP) = (2.26 + 3914.43 + 5.24)lb \times \frac{0.79\cancel{\%}}{100\cancel{\%}}$$

$$E(HAP) = (3921.93)lb \times 0.0079$$

$$\boxed{\boldsymbol{E(HAP) = 30.98\ lb}}$$

## 2.7    References

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

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

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

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

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

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

## 3.0    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.  **Open and prescribed burning operations result in the fugitive emissions of criteria pollutants and greenhouse gases.**

### 3.1.1    Open Burning

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

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

### 3.1.2    Prescribed Burns

Prescribed burning is a cost-effective method for the management of forests, ranges, and wetlands to accomplish natural resource management objectives.  These objectives may include the treatment of an area to reduce the potential for wildfires, removing logging residues, controlling insects and disease, increasing water yield, or controlling insect population and plant overgrowth without the use of herbicides and pesticides.  Prescribed burning is carried out by adhering to a strict plan that stipulates the required weather conditions and burning procedures, including an acceptable temperature range, moisture level, fuel used for ignition, and ignition method.

The combustion process associated with prescribed burning is composed of four phases: preheating, flaming, glowing, and smoldering.  Each phase produces different amounts of emissions relative to each other due to the variances in combustion temperatures and combustion efficiencies.  Therefore, the total emissions from prescribed burning depend on the time spent in

each phase. The preheating phase is typically the "cleanest" phase since few pollutants are emitted into the atmosphere. In contrast, the smoldering phase describes the portion of the process in which combustion is incomplete and inefficient, resulting in a much higher ratio of emitted pollutants per fuel consumed. The combustion efficiency varies in the flaming and glowing phases which, in turn, leads to varying amounts of emitted pollutants. A simple control volume for open and prescribed burns is provided in Figure 3-1.
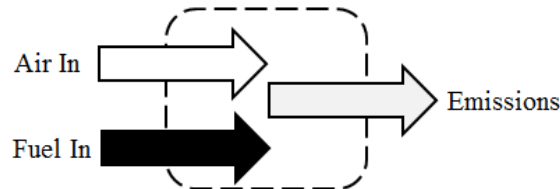


**Figure 3-1. Simplified Open/Prescribed Burn Control Volume**

## 3.2   NSPS Applicability

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

- Subpart Cb - Emissions Guidelines and Compliance Times for Large Municipal Waste Combustors that are Constructed on or Before September 20, 1994

- Subpart Eb – Standards of Performance for Large Municipal Waste Combustors for Which Construction is Commenced After September 20, 1994, or for Which Modification or Reconstruction is Commenced After June 19, 1996

- Subpart AAAA – Standards of Performance for Small Municipal Waste Combustion Units for Which Construction is Commenced After August 30, 1999, or for Which Modification or Reconstruction is Commenced After June 6, 2001

- Subpart BBBB – Emission Guidelines and Compliance Times for Small Municipal Waste Combustion Units Constructed on or Before August 30, 1999

- Subpart CCCC – Standards of Performance for Commercial and Industrial Solid Waste Incineration Units

- Subpart DDDD – Emissions Guidelines and Compliance Times for Commercial and Industrial Solid Waste Incineration Units

- Subpart EEEE – Standards of Performance for Other Solid Waste Incineration Units for Which Construction is Commenced After December 9, 2004, or for Which Modification or Reconstruction is Commenced on or After June 16, 2006

- Subpart FFFF – Emission Guidelines and Compliance Times for Other Solid Waste Incineration Units that Commenced Construction on or Before December 9, 2004.

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

## 3.3   Emission Factors

AP-42 provides several EFs for open and prescribed burning in Section 2.5 and Section 13.1, respectively.  Though these EFs 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 EFs used for emissions calculation may be used.

### 3.3.1   Open Burning

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

Air curtain incinerators, 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.  Air curtain incinerators are likely only to be used for open burning of agricultural materials.  Air curtain incinerator criteria pollutant and GHG EFs are provided in Table 3-1 and Table 3-2 respectively.  For additional information, refer to Section 2.1 of AP-42.

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

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

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

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

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

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

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

"---" – No Data Available.

**Table 3-2. GHG Emission Factors for Open Burning of Agricultural Materials**

| Agricultural Material [a] | Emission Factors (lb/ton) | | | |
|---|---|---|---|---|
| | $CO_2$ | $N_2O$ | $CH_4$ [b] | $CO_2e$ [c] |
| Field Crops | 2,149 | 0.08 | 5.4 | 2,307 |
| Grasses | 2,149 | 0.08 | 4.5 | 2,285 |
| Leaf Burning | 2,149 | 0.08 | 12 | 2,472 |
| Orchard Crops | 2,149 | 0.08 | 2.5 | 2,235 |
| Vine Crops | 2,149 | 0.08 | 1.7 | 2,215 |
| Weeds | 2,149 | 0.08 | 3.0 | 2,247 |
| Forest Residues - Unspecified | 3,615 | 0.14 | 5.7 | 3,799 |
| Forest Residues - Hemlock, Douglas Fir, Cedar | 3,615 | 0.14 | 1.2 | 3,686 |
| Forest Residues - Ponderosa Pine | 3,615 | 0.14 | 3.3 | 3,739 |
| **Air Curtain Incinerators** | | | | |
| Wood | 3,615 | 0.14 | 0.28 | 3,664 |

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

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

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

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

### 3.3.2   Prescribed Burns

EFs have been developed for prescribed burns based on the fuel type and combustion phase. Table 3-3 and Table 3-4 provide criteria pollutant and GHG EFs respectively for prescribed burns based on the types of materials combusted.

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

| Fuel or Fire Configuration | Combustion Phase | Emission Factor (lb/ton) | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | NO$_X$ [a] | CO | SO$_2$ [a] | Pb | VOC [b] | PM$_{10}$ | PM$_{2.5}$ |
| Chaparral | Flaming | --- | 119 | --- | --- | 17.2 | 16.5 | 13.5 |
| | Smoldering | --- | 197 | --- | --- | 30.6 | 24.7 | 21.6 |
| | Fire Average | 4.4 | 154 | 1.4 | --- | 19.6 | 20.1 | 17.3 |
| Conifer-Short Needle | Flaming | --- | 143 | --- | --- | 4.2 | 16.6 | 14.9 |
| | Smoldering | --- | 463 | --- | --- | 8.4 | 27.6 | 26.1 |
| | Fire Average | 4.8 | 312 | 2.1 | --- | 7.2 | 23.1 | 21.8 |
| Conifer-Long Needle | Flaming | --- | 89 | --- | --- | 3.6 | 11.5 | 10.0 |
| | Smoldering | --- | 285 | --- | --- | 9.6 | 36.7 | 34.2 |
| | Fire Average | 4.8 | 178 | 2.1 | --- | 6.4 | 25.0 | 22.0 |
| Conifer-Mixed | Flaming | --- | 53 | --- | --- | 3.2 | 11.7 | 9.6 |
| | Smoldering | --- | 273 | --- | --- | 13.2 | 25.3 | 23.6 |
| | Fire Average | 4.8 | 201 | 2.1 | --- | 9.8 | 20.5 | 18.8 |
| Hardwoods | Flaming | --- | 92 | --- | --- | 5.2 | 14.0 | 12.2 |
| | Smoldering | --- | 366 | --- | --- | 14.0 | 25.9 | 23.4 |
| | Fire Average | 2.0 [c] | 256 | 2.1 [c] | --- | 10.8 | 25.0 | 22.4 |
| Juniper | Flaming | --- | 82 | --- | --- | 5.5 | 15.3 | 13.9 |
| | Smoldering | --- | 250 | --- | --- | 15.5 | 25.8 | 23.8 |
| | Fire Average | 5.1 | 163 | 2.1 | --- | 10.4 | 20.4 | 18.7 |
| Sagebrush | Flaming | --- | 155 | --- | --- | 6.8 | 31.8 | 29.1 |
| | Smoldering | --- | 212 | --- | --- | 14.5 | 29.6 | 26.4 |
| | Fire Average | 4.4 | 206 | 1.4 | --- | 13.7 | 29.9 | 26.7 |
| Tractor-Piled Slash | Flaming | --- | 44 | --- | --- | 2.2 | 7.4 | 6.6 |
| | Smoldering | --- | 232 | --- | --- | 12.2 | 15.9 | 14.0 |
| | Fire Average | 4.8 | 153 | 2.1 | --- | 8.0 | 12.4 | 10.8 |
| Crane-Piled Slash | Flaming | --- | 101 | --- | --- | 8.2 | 13.6 | 11.8 |
| | Smoldering | --- | 232 | --- | --- | 20.2 | 33.2 | 31.0 |
| | Fire Average | 4.8 | 185 | 2.1 | --- | 15.2 | 25.6 | 23.4 |

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

a.  SOURCE: Johnson, T. J.; Yokelson, R.J.; Akagi, S. K.; Burling, I. R.; Weise, D. R.; Urbanski, S. P.; Stockwell, C. E.; Reardon, J.; Lincoln, E. N.; Profeta, L. T. M.; Mendoza, A.; Schneider, M. D. W.; Sams, R. L.; Williams, S. D.; Wold, C. E.; Griffith, D. W. T.; Cameron, M.; Gilman, J. B.; Warneke, C.; Roberts, J. M.; Veres, P.; Kuster, W.; de Gouw, J. 2013. Final Report for SERDP Project RC-1649: Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns. Technical Report PNNL-23025. Richland, WA: U.S. Department of Energy, Pacific Northwest National Laboratory. 126 p.

b.  Emission factor given for VOC is the same as that provided in source document for non-methane hydrocarbons.

c.  Urbanski, Shawn. 2014. Wildland Fire Emissions, Carbon, and Climate: Emissions Factors. Forest Ecology and Management. 317: 51-60.

"---" No data available

**Table 3-4. GHG Emission Factors for Prescribed Burns**

| Fuel or Fire Configuration | Combustion Phase | Emission Factor (lb/ton) | | | |
|---|---|---|---|---|---|
| | | $CO_2$ | $N_2O$ [a] | $CH_4$ | $CO_2e$ [b] |
| Chaparral | Flaming | 3326 | 0.46 | 3.4 | 3548 |
| | Smoldering | 3144 | 0.46 | 9.0 | 3506 |
| | Fire Average | 3257 | 0.46 | 5.7 | 3537 |
| Conifer-Short Needle | Flaming | 3385 | 0.46 | 4.6 | 3637 |
| | Smoldering | 2804 | 0.46 | 15.2 | 3321 |
| | Fire Average | 3082 | 0.46 | 11.0 | 3494 |
| Conifer-Long Needle | Flaming | 3401 | 0.46 | 3.0 | 3613 |
| | Smoldering | 2971 | 0.46 | 14.6 | 3473 |
| | Fire Average | 3202 | 0.46 | 8.2 | 3544 |
| Conifer-Mixed | Flaming | 3458 | 0.46 | 3.0 | 3670 |
| | Smoldering | 3023 | 0.46 | 17.6 | 3600 |
| | Fire Average | 3165 | 0.46 | 12.8 | 3622 |
| Hardwoods | Flaming | 3389 | 0.46 | 4.4 | 3636 |
| | Smoldering | 2851 | 0.46 | 19.6 | 3478 |
| | Fire Average | 3072 | 0.46 | 13.2 | 3539 |
| Juniper | Flaming | 3401 | 0.46 | 3.9 | 3636 |
| | Smoldering | 3050 | 0.46 | 20.5 | 3700 |
| | Fire Average | 3231 | 0.46 | 12.0 | 3668 |
| Sagebrush | Flaming | 3197 | 0.46 | 7.4 | 3519 |
| | Smoldering | 3118 | 0.46 | 12.4 | 3565 |
| | Fire Average | 3126 | 0.46 | 11.9 | 3561 |
| Tractor-Piled Slash | Flaming | 3492 | 0.46 | 2.4 | 3689 |
| | Smoldering | 3124 | 0.46 | 17.8 | 3706 |
| | Fire Average | 3271 | 0.46 | 11.4 | 3693 |
| Crane-Piled Slash | Flaming | 3349 | 0.46 | 9.4 | 3721 |
| | Smoldering | 3022 | 0.46 | 30.0 | 3909 |
| | Fire Average | 3143 | 0.46 | 21.7 | 3823 |

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

a.  SOURCE: Section 13.1 - "Wildfires and Prescribed Burning," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

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

## 3.4   Emissions Calculation

For both open and prescribed burning, the EFs provided above are sufficient enough for the general calculation of emissions.  However, for enhanced accuracy, refer to Section 2.5 or 13.1 of AP-42 for more information regarding species or region-specific EFs 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 EF as follows:

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

**Equation 3-1**

Where,

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

The total annual mass of material burned is an estimated value.  Best judgment should be used when making this 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.
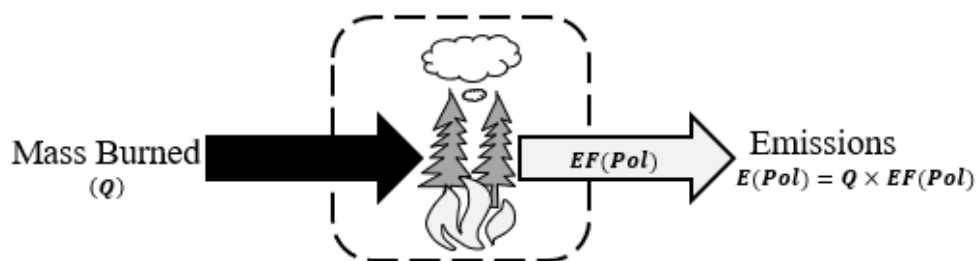


**Figure 3-2. Open/Prescribed Burn Control Volume**

## 3.5   Information Resources

The Base Civil Engineering organization is typically responsible for conducting open and prescribed burns on an installation.  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 United States Forest Service (USFS) 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, a USAF Base cleared 6.5 acres of land on base. The agricultural material on this land was primarily weeds, which were disposed of through open burning. Calculate the CO, VOC, $PM_{10}$, $PM_{2.5}$, and $CO_2e$ emissions from this operation.

**Step 1** – **Select and record the fuel loading factor.** Since the quantity of weeds was not provided in the problem statement, this value must be calculated. The first step involves recording the fuel loading factor which, according 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:

$$Q = A \times LF$$

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

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

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

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

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

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

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

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

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

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

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

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

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

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

### 3.6.2   Problem #2 (Prescribed Burn)

Last year, a USAF Base 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 USFS, 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 EFs may be used.  According to Table 3-3, the EFs for $PM_{2.5}$ for chaparral, mixed conifer, long needle conifer, sagebrush, and Douglas Fir are: **17.3, 18.8, 22.0, 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 EFs 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:

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

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

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

$$E(PM_{2.5})_{Long\ Needle\ Conifer} = 19\frac{ton}{yr} \times \frac{20\%}{100\%} \times 22.0\frac{lb}{ton} = 83.6\frac{lb}{yr}$$

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

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

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

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

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

$$\boxed{E(PM_{2.5}) = \boldsymbol{393.3}\frac{lb}{yr}}$$

## 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 Municial 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

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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

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## 4.0    CONSTRUCTION (CNST)

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

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

### 4.1   Introduction

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

The total emissions resulting from construction operations are the sum of the pollutant emitting activities that occur during each phase of construction.  Emissions from construction operations include emissions of the equipment involved in the construction activity, vehicle emissions from the workers commuting to the construction site, and emissions from the activity itself. Calculating emissions from each phase involves acquiring some site data such as the area and volume of the construction activity, and the average commuting distance for the workers. Programs such as the Air Conformity 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 Urban Emissions software, known as URBEMIS, 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; therefore, there is no one systematic approach to estimating emissions associated with construction.  Because of this uniqueness, the preferred Air Force method is to separate construction into typical phases that result in quantifiable emissions. Construction operations may be classified as having 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, as shown in Table 4-1. There are six construction emission classes that may contribute to the emissions for any specific construction phase, which include:

- Fugitive Dust,

- Construction Exhaust (Off-road equipment),

- Vehicle Exhaust (On-road vehicles),

- Worker Trips,

- Vendor Trips, and

- Off-Gassing.

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

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

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

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

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 to improve drainage around new or existing facilities.

Excavating and Trenching involves the digging and removing of soil and rock. This may be done to lay pipe or cable, or for drainage purposes. Excavated soil may be kept onsite for 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 increases during the building construction phase. The increase in vehicle exhaust is most often attributable to the influx of vendors making product deliveries to the construction site.

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

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

## 4.2   Emission Standards

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

## 4.3   Emissions Calculation

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

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

**Equation 4-1**

Where,

| | | |
|---|---|---|
| **E(Pol)** | = | Emissions of individual pollutant for entire construction project (lb) |
| **E(Pol)<sub>i</sub>** | = | Emissions of individual pollutant for an individual construction phase (lb) |
| **i** | = | Denotes the individual construction phase - i.e., Demolition, Site Grading, Trenching/Excavation, Building Constriction, Architectural Coatings, or Asphalt Paving |

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

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

**Equation 4-2**

### 4.3.1    Fugitive Dust

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

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

#### 4.3.1.1    Demolition Fugitive Dust Emissions

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

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

**Equation 4-3**

Where,

$E(PM_{10})$ = $PM_{10}$ emissions (lb)

**0.00042** = Emission factor (lb/ft$^3$)

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

**BH** = Height of building to be demolished (ft)

This equation is based on Table A9-9-H of the South Coast Air Quality Management District's (SCAQMD's) California Environmental Quality Act 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 rule, the grading area should be about twice the size of the building being constructed.**

**WD** = Work duration, estimated in <u>workdays</u> (days). **Note that this is workdays, not total duration days.**

### 4.3.2  Construction Exhaust (Off-Road Equipment) Emissions

Emissions are generated by the operation of off-road construction equipment, such as concrete saws and bulldozers.  Emissions from off-road equipment are estimated using the total operating time of the equipment and the appropriate EF.  The operating time is estimated using the per day average use in hours of each equipment type.  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 EFs, based on construction year, provided in Table 4-3 through Table 4-7.  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:

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

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

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

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

**Equation 4-6**

Where,

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

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

**Equation 4-7**

Where,

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

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

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


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

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

**Equation 4-8**

Where,

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


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

### 4.3.3.1  Demolition Round Trips

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

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

**Equation 4-9**

Where,

   **BA**     =  Area of building to be demolished (ft$^2$)
   **BH**     =  Height of building to be demolished (ft)
   **27**      =  Factor converting ft$^3$ to (yd$^3$/ft$^3$)
   **0.25**   =  Volume reduction factor (material reduced by 75% to account for air space)
   **HC**     =  Average truck hauling capacity per trip (yd$^3$/trip). **Assume 20 yd$^3$/trip if
                  unknown**.

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

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

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

**Equation 4-10**

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

**Equation 4-11**

Where,

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

### 4.3.3.3   Building Construction Material Round Trips

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

Military Family Housing:

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

**Equation 4-12**

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

**Equation 4-13**

Base Exchange, Commissary, etc.:

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

**Equation 4-14**

Offices or Industrial Buildings:

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

**Equation 4-15**

Where,

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

### 4.3.3.4  Paving Round Trips

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

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

**Equation 4-16**

Where,

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

### 4.3.4  Worker Commute Trip Emissions

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

### 4.3.4.1  VMT Estimates for Construction Phases Excluding Architectural Coatings

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

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

**Equation 4-17**

Where,

    **1**    =  Number of worker trips per day (trip/day)

    **WD**  =  Work duration (days)

    **WT**  =  Average worker round trip commute (miles/trip).  **Assume 20 miles/trip if unknown.**

    **1.25** =  Factor converting the number of construction equipment to the number of workers

    $N_i$    =  Number of total pieces of construction equipment in use

### 4.3.4.2   VMT Estimates for Architectural Coating

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

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

**Equation 4-18**

Where,

    **1**    =  Number of worker trips per day (trip/day)

    **WT**  =  Average worker round trip commute (miles/trip).  **Assume 20 miles/trip if unknown.**

    **SA**   =  Area of surface to be coated (ft$^2$)

    **800**  =  Assumed worker rate of paint application (ft$^2$/day)

### 4.3.5   Vendor Trip Emissions

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

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

Military Family Housing:

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

**Equation 4-19**

Base Exchange or Commissary.:

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

**Equation 4-20**

Offices or Industrial Buildings:

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

**Equation 4-21**

Where,

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

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

### 4.3.6   Off-Gassing Emissions

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

### 4.3.6.1   Architectural Coatings

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

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

Military Family Housing:

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

**Equation 4-22**

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

**Equation 4-23**

Where,

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

All Other Buildings:

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

**Equation 4-24**

Where,

**BA**   = Total building square footage (ft²)
**BH**   = Building Height (ft)
**4**     = Number of walls, assuming a square shaped building

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

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

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

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

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

### 4.3.6.2  Paving (Asphalt)

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

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

**Equation 4-25**

Where,

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

## 4.4   Information Resources

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

## 4.5   Example Problem

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

**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, PM$_{10}$ emissions are calculated as shown:

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

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

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

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

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

**Step 4 – Select and record the appropriate EFs.** Construction equipment EFs for 2020 are provided in Table 4-3. The $PM_{10}$ EFs for the tractor, dozer, and saw are **0.013, 0.063, and 0.02 lb/hr, respectively.**

**Step 5 – Calculate construction exhaust emissions.** Using the EFs 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:

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

$E(PM_{10})_{Construction\ Exhaust}$
$$= \left[\left(20\ days \times 6\ \frac{hr}{day} \times 2 \times 0.013\ \frac{lb}{hr}\right) + \left(20\ days \times 4\ \frac{hr}{day} \times 1 \times 0.063\ \frac{lb}{hr}\right)\right.$$
$$\left. + \left(20\ days \times 5\ \frac{hr}{day} \times 2 \times 0.02\ \frac{lb}{hr}\right)\right]$$

$$\boldsymbol{E(PM_{10})_{Construction\ Exhaust}} = [(3.12\ lb) + (5.04\ lb) + (4\ lb)] = \boldsymbol{12.16\ lb}$$

**Step 6 – Calculate the number of round trips made that contributed to vehicle exhaust.**
The demolition phase of construction also results in vehicle exhaust emissions that must be calculated. The first step in making this calculation is to determine the number of round trips made. Using the area and height of the demolished building and assuming the truck hauling capacity is 20 yd³/trip, an estimate of the number of round trips may be calculated using Equation 4-9:

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

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

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

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

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

**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 4-8:

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

$$\boldsymbol{VMT} = 41.67\ trips \times 20\ \frac{miles}{trip} = \boldsymbol{833.3\ miles}$$

**Step 8 – Select and record the appropriate EF.** The vehicle mix for vehicle exhaust emissions is assumed to be 100% HDDV. For CY2020, the $PM_{10}$ EF in Alabama, according to the 2020 *Air Emissions Guide for Air Force Mobile Sources*, is **0.166 g/mile.**

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

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

$$E(PM_{10})_{Vehicle\ Exhaust} = 833.3\ miles \times 0.166 \frac{g}{mile} \times 0.002205 \frac{lb}{g}$$

$$\boldsymbol{E(PM_{10})_{Vehicle\ Exhasut}} = \boldsymbol{0.305\ lb}$$

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

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

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

**Step 11 – Select and record the appropriate EFs.**  Assuming a mix of LDGV and LDGT for worker vehicle types, the EFs for $PM_{10}$ from the *Air Emissions Guide for Air Force Mobile Sources* are **0.006 and 0.008 g/miles respectively**.

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

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

$$EF(PM_{10}) = \sum \left\{ \left( \frac{50\%}{100\%} \right) \times 0.006 \left( \frac{g}{mile} \right) \times \left[ 1 - \frac{0\%}{100\%} \right] \right\} + \left\{ \left( \frac{50\%}{100\%} \right) \times 0.008 \left( \frac{g}{mile} \right) \times \left[ 1 - \frac{0\%}{100\%} \right] \right\}$$

$$\boldsymbol{EF(PM_{10})} = \sum \left\{ 0.5 \times 0.006 \left( \frac{g}{mile} \right) \right\} + \left\{ 0.5 \times 0.008 \left( \frac{g}{mile} \right) \right\} = \boldsymbol{0.007 \frac{g}{mile}}$$

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

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

$$E(PM_{10})_{Worker\ Trips} = 2000\ \cancel{miles} \times 0.007 \frac{\cancel{g}}{\cancel{mile}} \times 0.002205 \frac{lb}{\cancel{g}} = 0.0309\ lb$$

**Step 14 – Calculate total PM₁₀.**  The final step is to sum the $PM_{10}$ emissions from each class comprising the demolition phase of construction using Equation 4-2:

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

$$E(PM_{10})_{Demolition} = 37.8\ lb + 12.16\ lb + 0.305\ lb + 0.0309\ lb + 0 + 0$$

$$\boxed{E(PM_{10})_{Demolition} = 50.3\ lb}$$

**Table 4-3. Criteria Pollutant Emission Factors for Off-Road Equipment - 2020**

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | VOC [a] | $PM_{10}$ [b] | $PM_{2.5}$ [b] | $CO_2e$ [c] |
| 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 |

Notes for Table 4-3 through Table 4-8 follow Table 4-8.

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

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | VOC [a] | $PM_{10}$ [b] | $PM_{2.5}$ [b] | $CO_2e$ [c] |
| 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 |

Notes for Table 4-3 through Table 4-8 follow Table 4-8.

**Table 4-5. Criteria Pollutant Emission Factors for Off-Road Equipment - 2022**

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | VOC [a] | $PM_{10}$ [b] | $PM_{2.5}$ [b] | $CO_2e$ [c] |
| 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 |

Notes for Table 4-3 through Table 4-8 follow Table 4-8.

**Table 4-6. Criteria Pollutant Emission Factors for Off-Road Equipment - 2023**

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | NO$_X$ | CO | SO$_X$ | VOC [a] | PM$_{10}$ [b] | PM$_{2.5}$ [b] | CO$_2$e [c] |
| 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 |

Notes for Table 4-3 through Table 4-8 follow Table 4-8.

**Table 4-7. Criteria Pollutant Emission Factors for Off-Road Equipment - 2024**

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | VOC [a] | $PM_{10}$ [b] | $PM_{2.5}$ [b] | $CO_2e$ [c] |
| 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 |

Notes for Table 4-3 through Table 4-8 follow Table 4-8.

**Table 4-8. Criteria Pollutant Emission Factors for Off-Road Equipment - 2025**

| Equipment | Emission Factors (lb/hr) | | | | | | |
|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | VOC [a] | $PM_{10}$ [b] | $PM_{2.5}$ [b] | $CO_2e$ [c] |
| 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.

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

b.     Source provides emission factors for total particulate which is conservatively assumed to be equal to $PM_{10}$ and $PM_{2.5}$.

c.     $CO_2e$ emission factor is the sum of the product of $CO_2$ and $CH_4$ and their respective Global Warming Potentials (GWP). GWP for $CO_2$ and $CH_4$ 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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## 5.0    PORTABLE AND SEASONAL RECIPROCATING INTERNAL COMBUSTION ENGINES

➤  *Point* Source

## 5.1    Introduction

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

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

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

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

cylinder during the exhaust stroke and returns to the starting position of the induction stroke so the cycle may be repeated. 2-stroke engines can operate with just one revolution of the crankshaft because induction of the air or air/fuel mixture occurs concurrently with the release of the exhaust gas.

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

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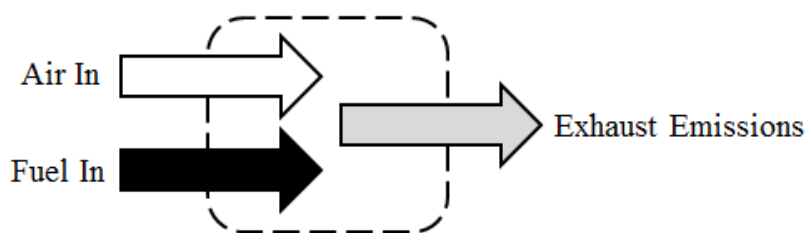


**Figure 5-1. Simplified Portable RICE Control Volume**

## 5.2   Emission Factors

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

Emissions estimates may be made based on the heating value or sulfur content of the fuels used to operate the RICE.  **Typical fuel data and RICE EFs for portable use equipment are provided in the "Stationary Internal Combustion" section of the *Air Emissions Guide for Air Force Stationary Sources*.**  For simplicity, the EFs are provided for two timespans for engines manufactured prior to 2007 (or 2011 for engines >3,000 hp and displacement ≤10 L/cylinder) and those engines manufactured or modified after this date.  Though this simplification may lead to reduced emissions, as opposed to using AP-42 EFs, it is possible to reduce emissions further by consulting the Code of Federal Regulations directly to determine additional thresholds and implementation years not given.

## 5.3   Emission Calculation

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

### 5.3.1   Fuel Consumption Method

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

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

**Equation 5-1**

Where,

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

A detailed representation of the emissions from stationary RICE engines is provided in Figure 5-2.
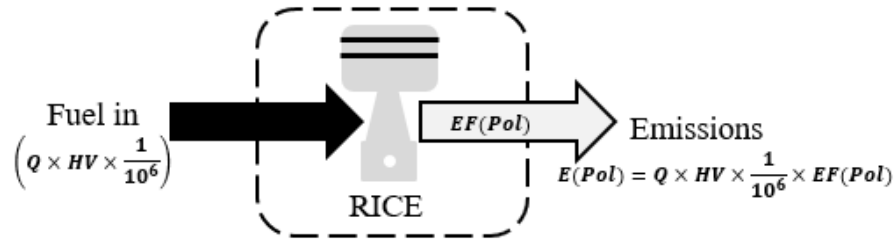
**Figure 5-2. Portable and Seasonal Equipment Use Control Volume - Fuel Consumption Method**

### 5.3.2 Load Factor Method

To calculate the most accurate emissions for portable and seasonal use engines, the first step is to gather the required data and select the appropriate EF. **To use the load factor method, the engine's rated power, operating time, and typical load factor must be known. Actual site-specific loading factors should be used whenever possible.** With the selected EF and loading factor, the RICE 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 Source Guide (lb/hp-hr) |

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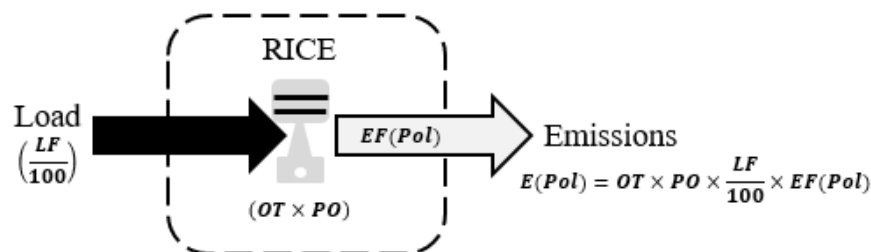


**Figure 5-3. Portable and Seasonal Equipment Use Control Volume - Load Factor Method**

## 5.4    Information Resources

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


## 5.5    Example Problems

### 5.5.1    Problem #1 – Fuel Consumption Method

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

**Step 1 – Select and record EF and fuel Heating Value.**  The EFs for diesel-fired engines are provided in the 2020 *Air Emissions Guide for Air Force Stationary Sources*.  The $NO_X$ EF is **7.62E-01 lb/MMBtu.**  The heating value of diesel is given as **138,000 Btu/gal.**

**Step 2 – Choose a calculation method and record the appropriate equation.**  For demonstration purposes, the method was assigned in the problem statement, however, it should be noted that this is the most appropriate method to use since the power output and load factor are not provided while the annual fuel consumption is 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 EF, $NO_X$ emissions may be calculated using Equation 5-1.

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

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

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

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

### 5.5.2   Problem #2 – Load Factor Method

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

**Step 1 – Select and record EF.**  EFs are provided in the 2020 *Air Emissions Guide for Air Force Stationary Sources*.  For a 1,250 hp diesel engine manufactured in 2004 with 2.0 L per cylinder displacement, the VOC EF is **7.16E-04 lb/hp-hr**.

**Step 2 – Choose a calculation method and record the appropriate equation.**  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:

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

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

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

## 5.6    References

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

40 CFR 98 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

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

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

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

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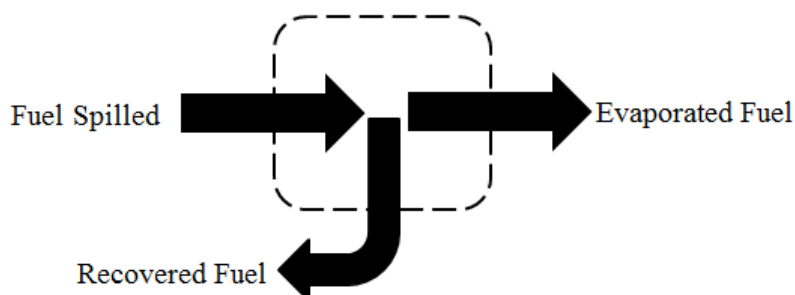


**Figure 6-1. Simplified Fuel Spill Control Volume**

### 6.2    Emissions Calculations

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

#### 6.2.1    VOC Emissions Calculations

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

$$E(VOC) = (Q_S - Q_R) \times D = (Q_S - Q_R) \times SG \times 8.33$$

**Equation 6-1**

Where,

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

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

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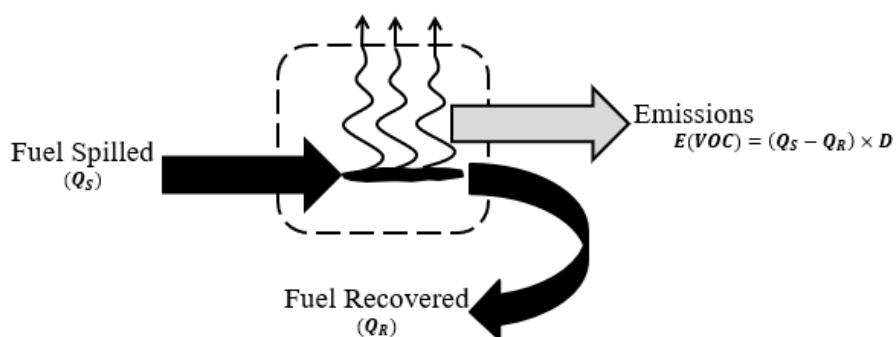


**Figure 6-2. Fuel Spill Control Volume**

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

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

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

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

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

## 6.2.2   HAP Emissions Calculations

When calculating emissions from fuel spills, the conservative assumption is that all unrecovered fuel evaporates.  The organic HAP emissions are calculated based on the <u>liquid-phase</u> speciation of the fuel.  This is accomplished using the weight fraction of the HAP as shown in Equation 6-2.

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

**Equation 6-2**

Where,

| | | |
|---|---|---|
| **E(HAP)** | = | Annual emissions of specific HAP (lb/yr) |
| **E(VOC)** | = | Annual emissions of VOCs as calculated in Equation 6-1 (lb/yr) |
| **WP(HAP)** | = | Weight percent of the HAP in the <u>liquid</u> fuel (%) |

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

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

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

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

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

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

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

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

"---" Indicates No Data Available

## 6.3   Information Resources

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

## 6.4   Example Problem

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

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

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

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

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

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

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

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

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

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

$$E(Benzene) = 1,167.25 \frac{lb}{yr} \times \frac{0.0336\%}{100\%}$$

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

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

$$\boldsymbol{E(Cumene) = 1,167.25 \frac{lb}{yr} \times \frac{0.18\%}{100\%} = 2.11 \frac{lb}{yr}}$$

$$\boldsymbol{E(Ethylbenzene) = 1,167.25 \frac{lb}{yr} \times \frac{0.158\%}{100\%} = 1.86 \frac{lb}{yr}}$$

$$\boldsymbol{E(Fluorene) = 1,167.25 \frac{lb}{yr} \times \frac{0.00342\%}{100\%} = 0.04 \frac{lb}{yr}}$$

$$\boldsymbol{E(Isooctane) = 1,167.25 \frac{lb}{yr} \times \frac{0.00122\%}{100\%} = 0.01 \frac{lb}{yr}}$$

$$\boldsymbol{E(Naphthalene) = 1,167.25 \frac{lb}{yr} \times \frac{0.266\%}{100\%} = 3.13 \frac{lb}{yr}}$$

$$\boldsymbol{E(Phenylbenzene) = 1,167.25 \frac{lb}{yr} \times \frac{0.0674\%}{100\%} = 0.79 \frac{lb}{yr}}$$

$$\boldsymbol{E(Pyrene) = 1,167.25 \frac{lb}{yr} \times \frac{0.0000124\%}{100\%} = 0.0001 \frac{lb}{yr}}$$

$$\boldsymbol{E(Toluene) = 1,167.25 \frac{lb}{yr} \times \frac{0.218\%}{100\%} = 2.54 \frac{lb}{yr}}$$

$$\boldsymbol{E(Xylene) = 1,167.25 \frac{lb}{yr} \times \frac{1.18\%}{100\%} = 13.77 \frac{lb}{yr}}$$

**Step 5** – **Calculate total HAPs emitted.** Sum the HAPs calculated in Step 4.

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

$$E(Total\ HAP) = (2.11 + 1.86 + 0.04 + 0.01 + 3.13 + 0.79 + 0.0001 + 2.54 + 13.77) \frac{lb}{yr}$$

$$\boxed{\boldsymbol{E(Total\ HAP) = 24.2 \frac{lb}{yr}}}$$

## 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

# 7.0    HOT MIX ASPHALT PLANTS (HMA)

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

## 7.1    Introduction

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

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

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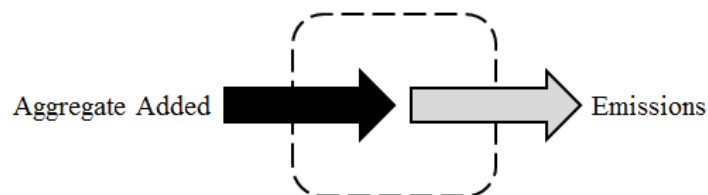


**Figure 7-1. Simplified HMA Plants Emissions Control Volume**

## 7.2   NSPS Applicability

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

## 7.3   Warm Mix Asphalt (WMA) Plants

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

## 7.4   Emission Factors

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

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

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

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

a. Control Device used: Fabric Filter

b. $CO_2e$ emission factors are the sum of the product of carbon dioxide ($CO_2$), Methane ($CH_4$), and nitrous oxide ($N_2O$) and their respective Global Warming Potentials (GWP). The GWP for $CO_2$, $CH_4$, and $N_2O$ are 1, 25, and 298 respectively. Emission factors taken from AP-42

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

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

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

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

b. Control Device used: Fabric Filter

c. $CO_2e$ emission factors are the sum of the product of carbon dioxide ($CO_2$), Methane ($CH_4$), and nitrous oxide ($N_2O$) and their respective Global Warming Potentials (GWP). The GWP for $CO_2$, $CH_4$, and $N_2O$ are 1, 25, and 298 respectively. Emission factors taken from AP-42

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

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

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

"---" - Indicates No Data Available

## 7.5   Emissions Calculations

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

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

**Equation 7-1**

Where,

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

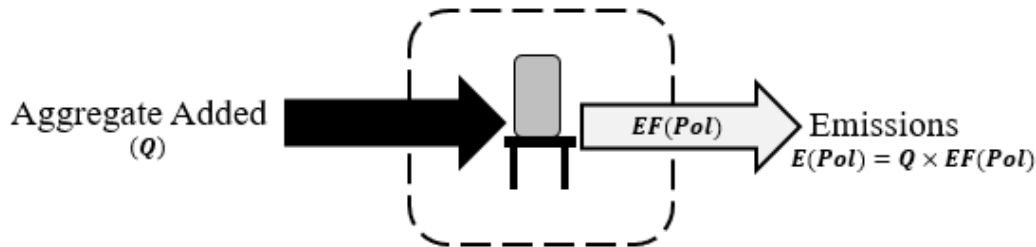A detailed control volume depicting emissions from HMA plants is provided in Figure 7-2.



**Figure 7-2. HMA Control Volume**

## 7.6   Information Resources

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

## 7.7   Example Problem

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

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

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

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

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

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

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

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

$$\boxed{E(\mathbf{Formaldehyde}) = \mathbf{154.66 \; lb/yr}}$$

## 7.8   References

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

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

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

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

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## 8.0    CONCRETE BATCH PLANT (CB)

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

### 8.1   Introduction

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

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



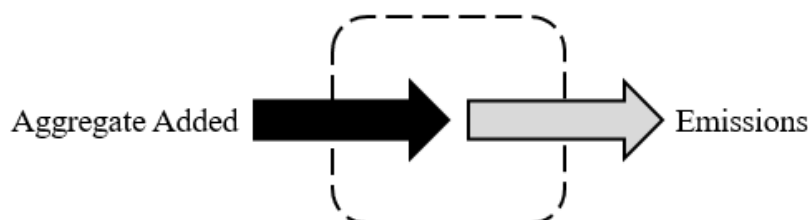**Figure 8-1. Simplified Concrete Batch Plant Emissions Control Volume**

### 8.2   Emission Factors

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

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

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

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

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

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

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

ND = No data

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

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

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

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

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

## 8.3   Emissions Calculations

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

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

**Equation 8-1**

Where,

      **E(Pol)**   =  Annual emissions of pollutant (ton/yr)

      **Q**         =  Annual quantity of asphalt produced (ton/yr)

      **EF(Pol)** =  Emission factor for a specific pollutant (lb/ton)


A detailed control volume depicting the emissions from concrete batch plants is given in
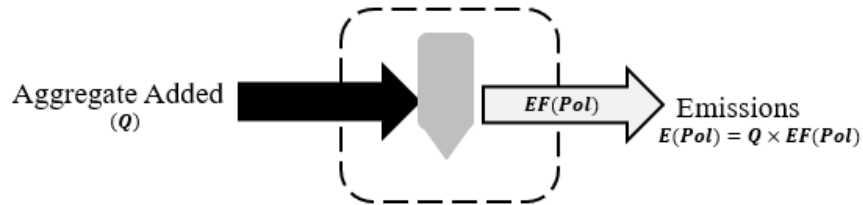


**Figure 8-2. Concrete Batch Plant Control Volume**


## 8.4   Information Resources

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


## 8.5   Example Problems

### 8.5.1   Problem #1

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

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

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

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

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

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

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

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

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

### 8.5.2   Problem #2

A USAF Base needs to calculate PM$_{2.5}$ emissions from their CB plant operations that include weigh hopper loading and central mix loading. Base Civil Engineering reports that the on-base CB plant is a controlled central mix plant. The maximum production rate was 210 tons/hr, and the plant was estimated to have operated for approximately 900 hours/yr. According to Chapter 11 of AP-42, for conversion purposes, there are 4,024 pounds of material in one cubic yard of concrete and 2,000 pounds in one ton.

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

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

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

**Step 2 - Select and record the appropriate EFs.** Table 8-2 lists the EFs for PM$_{2.5}$ as **0.0026 lb/yd³** for weigh hopper loading and **0.0010 lb/yd³** for central mix loading.

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

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

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

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

**Step 4** - Sum the emissions calculated to determine total PM$_{2.5}$ from weigh hopper loading and central mix loading.

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

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

## 8.6   References

Section 11.12 - "Concrete Batching," Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, June 20.

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## 9.0    SITE REMEDIATION (RDL)

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

### 9.1    Introduction

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

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

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

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

### 9.2    Air Quality Regulatory Requirements

The emissions of concern for site remediation are HAPs.  NESHAPs have been developed that apply to site remediation.  40 CFR 63 subpart GGGGG, also known as the Site Remediation Rule, describes the standards required of any applicable facilities that 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.  The Site Remediation Rule states that any site remediation conducted under the authority of CERCLA/RCRA is exempt from these standards.  Consult the CFR to determine if exemptions apply or to verify compliance with standards.

### 9.2.1    Applicable or Relevant and Appropriate Requirements (ARARs)

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

- Air quality designation of the site's location (i.e., attainment, nonattainment, unclassified, transport) for each NAAQS,

- Classification of each designated nonattainment area (e.g., marginal, moderate, or serious),

- Whether construction or modification of their stationary source commenced after the date of publication of regulations (or proposed regulations) prescribing a standard of performance that governs such source,

- Required control measures including 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)

### 9.2.2    ARAR Waivers

Waivers, which by statute apply to on-site CERCLA remedial actions, must be invoked for each ARAR that will not be attained.  Because removal actions must comply with ARARs to the extent practicable, waivers are also available for removal actions.  Six statutory waivers are codified under 40 CFR § 300.430(f)(1)(ii)(C)(1)-(6) and include the following (see also 55 *FR*8747–50):

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

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

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

### 9.2.3   Major Source of Hazardous Air Pollutants (HAPs)

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

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

- Emission data, including the pollutants expected to be emitted and the rate of emission for each pollutant (e.g., TCE emissions rate from all air strippers at the site),

- Consideration of health risks from the execution of the remedy as well as from the uncontrolled site,

- Control alternatives and their costs,

- Ozone attainment status, and

- Potential air ARARs.

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

### 9.2.4   National Ambient Air Quality Standards

NAAQS are standards established by the EPA under authority of the CAA that apply for outdoor air throughout the country. 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.

### 9.2.5   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.

### 9.2.6   RCRA Subparts AA, BB, and CC

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

- For Subpart AA, the contaminated water managed in a specified operation has an annual average total organic concentration of 10 ppmw or greater; (DOE, 1993a) or

- For Subpart BB, the equipment contains or contacts hazardous wastes with organic concentrations of at least 10 percent by weight; (DOE, 1993b) and

- The contaminated ground water qualifies as hazardous waste; and

- The contaminated ground water is being managed at a RCRA Treatment, Storage, and Disposal Facility (TSDF) or 90-day generator.

Although not pertinent to RCRA corrective actions, Subparts AA and BB control requirements may 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 percent 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.

### 9.3   Remediation Technologies

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

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

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

## 9.4   Emission Sources

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

### 9.4.1   Process Vents

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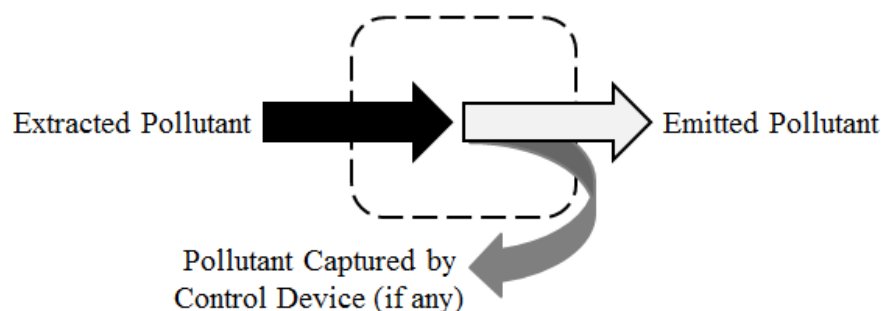
**Figure 9-1. Simple Control Volume for Emissions from Site Remediation**

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

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

### 9.4.1.1   Soil Vapor Extraction (SVE)

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

the target chemical after it has been corrected with the scaling factor, but this may need to be performed manually for an accurate measure of the chemical concentration.

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

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

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

**Equation 9-1**

Where,

| | | |
|---|---|---|
| **E(Pol)** | = | Emissions of a pollutant (lb/yr) |
| **Q** | = | Flow rate of the extracted air (ft$^3$/min) |
| **C(Pol)** | = | Concentration of the pollutant in the extracted air (ppmv) |
| **MW(Pol)** | = | Molecular Weight of the pollutant (lb/lb-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:

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

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

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

Emitted Pollutant

Control Device

Extracted Pollutant
$(Q)$

Captured Pollutant

$$\left[Q \times C(Pol) \times MW(Pol) \times (1.581 \times 10^{-7}) \times t \times \frac{CE}{100}\right]$$
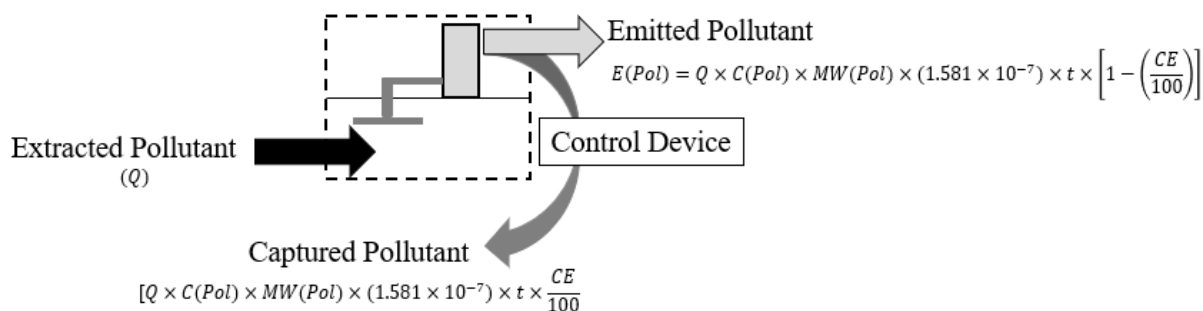
**Figure 9-2. Soil Vapor Extraction Control Volume**

### 9.4.1.2   Air Stripping (AS)

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

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

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

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

**Equation 9-2**

Where,

| | | |
|---|---|---|
| **Q** | = | Groundwater pumping rate (gal/min) |
| **C(Pol)** | = | Concentration of the pollutant in the groundwater (mg/L) |
| **RE** | = | Removal efficiency of the air stripper (%) |
| **100** | = | Factor converting percent to a fraction (%) |
| **5.042x10$^{-4}$** | = | Equation constant [(lb L min)/(mg gal hr)] |

The equation constant was derived as follows:

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

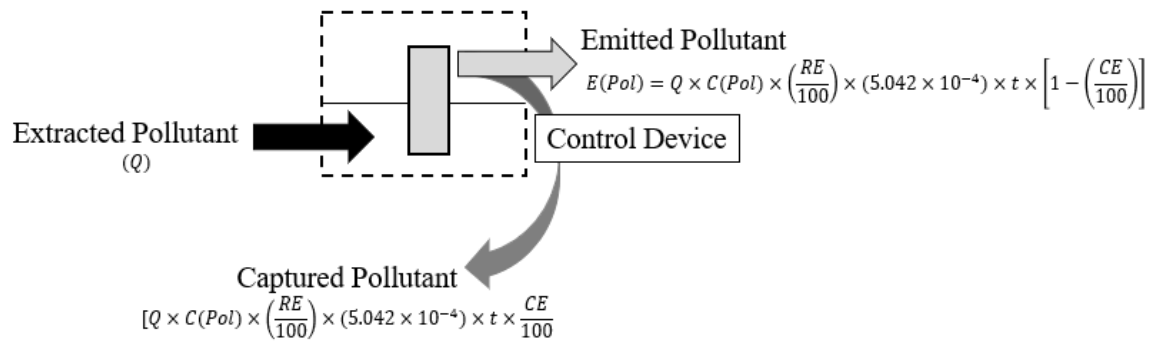A detailed control volume of emissions from air stripping is provided in Figure 9-3.



**Figure 9-3. Air Stripping Control Volume**

### 9.4.2   Remediation Material Management Units

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

### 9.4.3   Equipment Leaks

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

## 9.5   Information Resources

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

## 9.6   Example Problems

### 9.6.1   Problem #1 (Soil Vapor Extraction)

A USAF Base is looking to calculate air emissions from a remediation site located on base.  SVE was used to remove perchloroethylene (PCE) from one extraction well at this location.  The SVE process was in operation for approximately 1200 hours with an air flow rate of 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 the data required for emissions calculation is provided in the problem statement.  Using this data and Equation 9-1, emissions may be calculated as follows:

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

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

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

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

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

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

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

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

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

### 9.6.2   Problem #2 (Air Stripping)

In addition to the emissions resulting from the SVE site on base, the same USAF Base is also concerned with emissions at an alternate site where JP-8 was removed from groundwater. This operation was run for about 1120 hours and pumped at an average rate of 45 gal/min. Site testing indicated that the average concentration of VOCs in the groundwater was approximately 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.** Using Equation 9-2, VOC emissions are calculated as follows:

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

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

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

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

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

$$\boxed{E(Pol) = 3862.5\frac{lb}{yr}}$$

## 9.7    References

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

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

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

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

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# 10.0  LAND USE CHANGE

➢ *Carbon Dioxide Sequestration*

## 10.1  Introduction

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

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

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

## 10.2  Background Information

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

Over time, this balance of intake and emission has kept the amount of $CO_2$ in the atmosphere relatively cyclic with the maximum $CO_2$ level below 300 ppm. However, the amount of $CO_2$ in the atmosphere has increased steadily since the beginning of the Industrial Revolution, with $CO_2$ concentrations rising especially sharply in the latter half of the 20th century. Figure 10-1. Carbon Dioxide Level Over Time, shows $CO_2$ levels during the last three glacial cycles, as reconstructed from ice cores. Since 1950 there has been a dramatic increase in $CO_2$ levels well beyond the 300 ppm of the past natural cycles which has been directly linked to human activities and climate change.
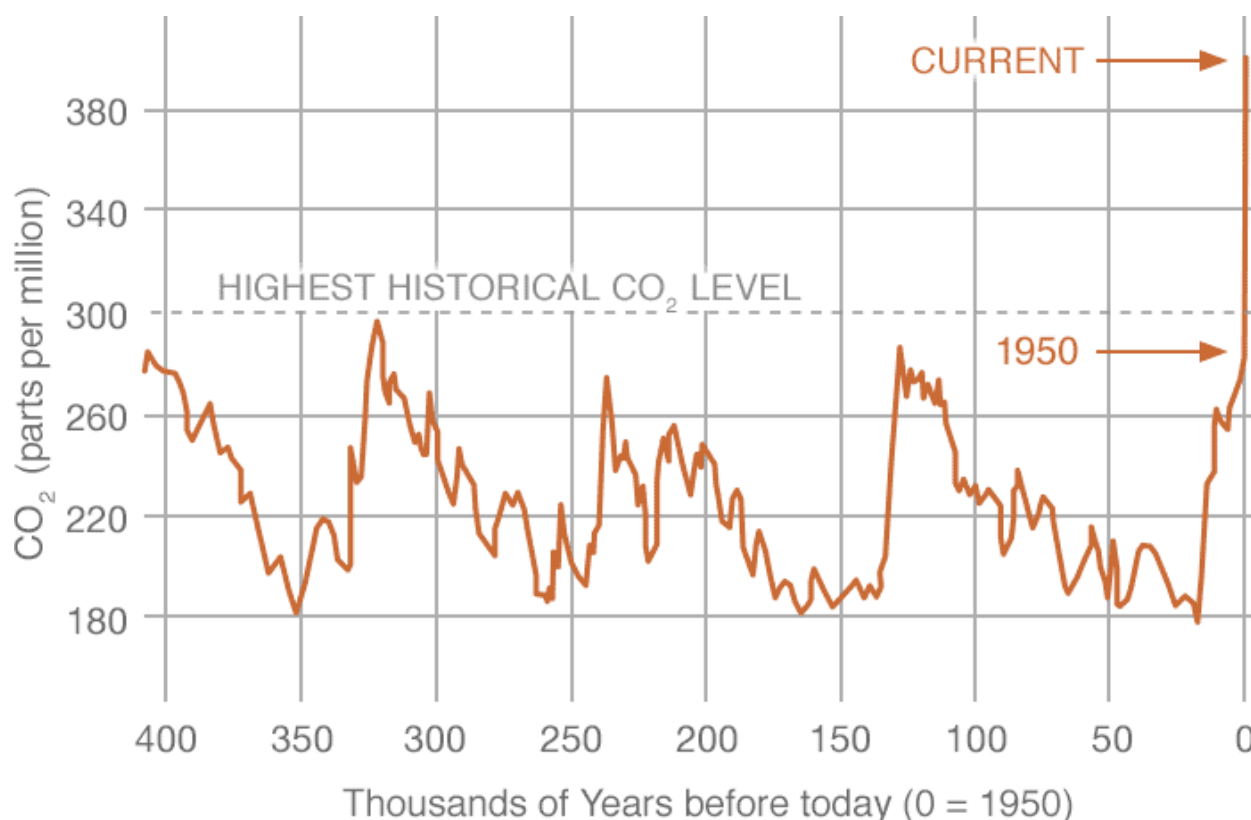


**Figure 10-1. Carbon Dioxide Level Over Time**

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

Human activities associated with changes to land use may directly impact local air quality by reducing the environment's natural ability to sequester (remove and store) air pollutants.

Solar radiation from the sun and the presence of GHGs in Earth's atmosphere play a large role in the temperature of the planet. Solar radiation passes through the atmosphere and warms Earth's surface. Naturally occurring greenhouse gases, such as $CO_2$, $CH_4$ and even water vapor ($H_2O$)

create an insulating layer in the atmosphere, which helps prevent the heat from escaping Earth. This makes it possible for the Earth to be warm enough to sustain life.

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

## 10.3  Calculation Methodology

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

### 10.3.1  USGS Methodology Background

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

For these regional assessments, three biogeochemical models were run in an ensemble fashion on the General Ensemble Biogeochemical Modeling System (GEMS) platform.  These biogeochemical models were used to simulate ecosystem biogeochemical cycles and estimate carbon flux values.  The biogeochemical models used are the Century version 4.0, the Erosion Deposition Carbon Model (EDCM), and the Land Greenhouse-Gas Accounting Tool (LGAT).

Included in these USGS reports is an assessment of the amount of carbon dioxide sequestered by various land uses, such a forest land, grassland, wetland, and agriculture for each region.  It is these values that serve as the basis for this methodology.

### 10.3.2  Sequestration Factors

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

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

| Region | Land Type | Annual CO$_2$ Sequestration (lb CO$_2$/acre) |
|---|---|---|
| **Great Plains Average** [a] | Forests | 6297.3 |
| | Wetlands | 1704.4 |
| | Agricultural Lands | 615.0 |
| | Grasslands/shrublands | 438.4 |
| | Impervious Surfaces (e.g., buildings, parking lots, etc.) | 0.0 |
| **Western Average** [b] | Forests | 2355.4 |
| | Wetlands | NA |
| | Agricultural Lands | 1243.1 |
| | Grasslands/shrublands | 523.4 |
| | Impervious Surfaces (e.g., buildings, parking lots, etc.) | 0.0 |
| **Eastern Average** [c] | Forests | 5070.6 |
| | Wetlands | 4318.1 |
| | Agricultural Lands | 392.6 |
| | Grasslands/shrublands | 1341.2 |
| | Impervious Surfaces (e.g., buildings, parking lots, etc.) | 0.0 |

a.  SOURCE: Zhu, Zhiliang, ed., Bouchard, Michelle, Butman, David, Hawbaker, Todd, Li, Zhengpeng, Liu, Jinxun, Liu, Shuguang, McDonald, Cory, Reker, Ryan, Sayler, Kristi, Sleeter, Benjamin, Sohl, Terry, Stackpoole, Sarah, Wein, Anne, and Zhu, Zhiliang, 2011, Baseline and projected future carbon storage and greenhouse-gas fluxes in the Great Plains region of the United States: U.S. Geological Survey Professional Paper 1787, 28 p. (Also available at http://pubs.usgs.gov/pp/1787/.)

b.  SOURCE: Zhu, Zhiliang, and Reed, B.C., eds., 2012, Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1797, 192 p. (Also available at http://pubs.usgs.gov/pp/1797/.)

c.  SOURCE: Zhu, Zhiliang, and Reed, B.C., eds., 2014, Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the eastern United States: U.S. Geological Survey Professional Paper 1804, 204 p., http://dx.doi.org/10.3133/pp1804.
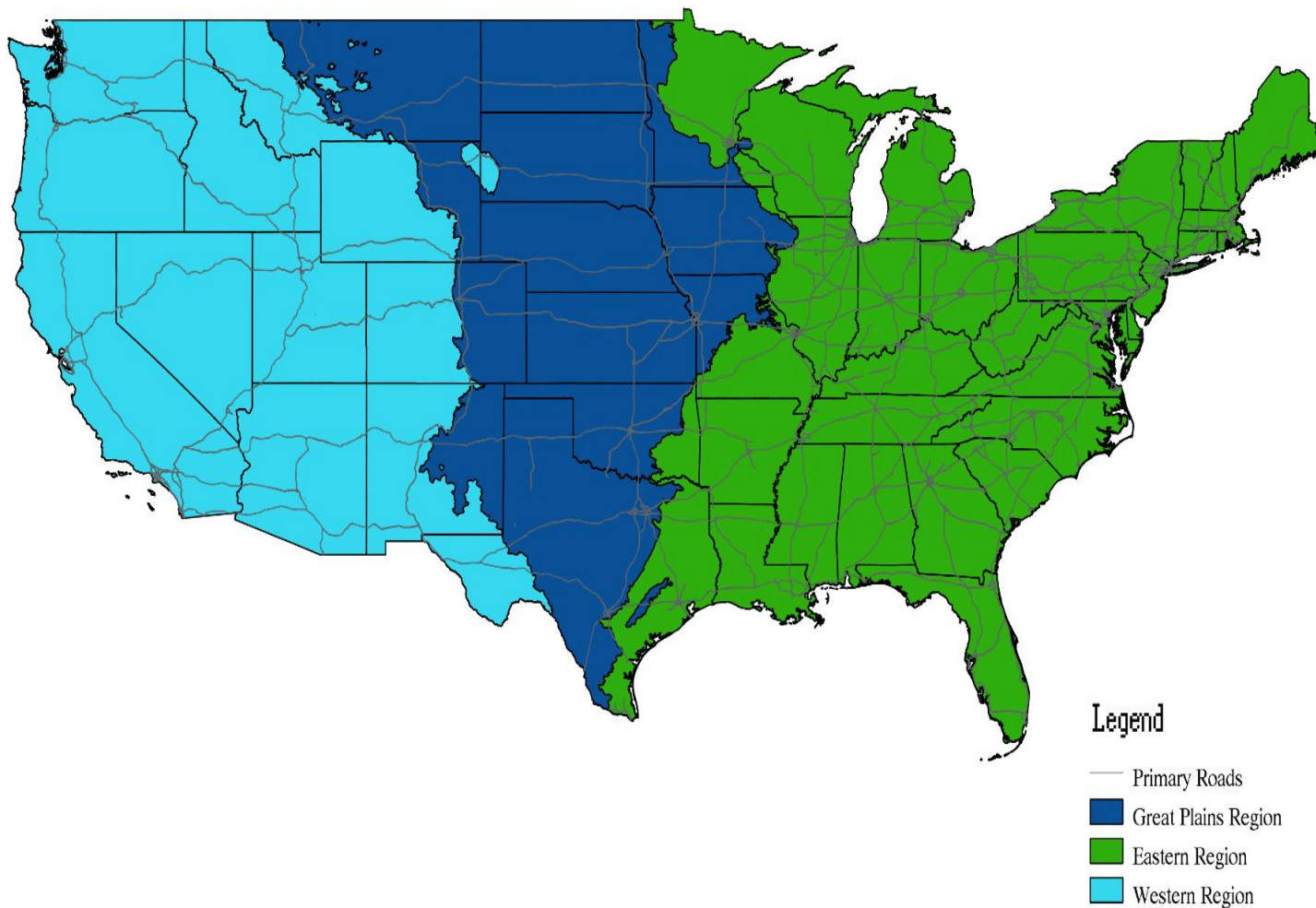
**Figure 10-2. Regional Map for Land Use Change Sequestration Factors**

### 10.3.3  Calculating Sequestration

The USGS methodology can be used to calculate the carbon dioxide sequestration of a land use change.  This methodology is designed to be used for instances when land is being changed from one use to another, such as a grassland being converted into a forestland.  Sequestration, both gains and losses from changing land use, can be calculated using Equation 10-1.  Positive values for sequestration change indicate that the land use change has increased the sequestration of the land.  Negative values indicate that the land use change resulted in a decrease of sequestration, meaning less pollutants such as $CO_2$ are removed and stored.  Use Figure 10-2. Regional Map for Land Use Change Sequestration Factors to identify the ecoregion that the land use change is occurring in and then use the sequestration factors from Table 10-1 as inputs into Equation 10-1 to calculate the change in sequestration.

$$\Delta S = \left(A_f \times SF_f\right) - \left(A_i \times SF_i\right)$$

**Equation 10-1**

Where:

| | | |
|---|---|---|
| $\Delta S$ | = | Sequestration Change (lb $CO_2$/yr) |
| $A_f$ | = | Area of land after land use change (acre) |
| $SF_f$ | = | Sequestration Factor of land type after change (lb $CO_2$/acre-yr) |
| $A_i$ | = | Area of land before land use change (acre) |
| $SF_i$ | = | Sequestration Factor of land type before change (lb $CO_2$/acre-yr) |

## 10.4  Example Problems

### 10.4.1  Increase in Sequestration Problem #1

A USAF Base is in Florida.  The Base is considering converting an existing 30 acres of grassland into forestland.

**Step 1:  Determine the region the land use change is occurring.**  Since this USAF is in Florida, it is in the Eastern Region.

**Step 2:  Select the appropriate sequestration factors from Table 10-1.**  For the Eastern Region, the sequestration factor for **grassland is 1341.2 lb $CO_2$/acre-year**.  The sequestration factor for **forestland is 5070.6 lb $CO_2$/acre-year**.

**Step 3:  Use Equation 10-1 to determine the effect of converting the 30 acres of grassland into forestland**.

$$\Delta S = \left(A_f \times SF_f\right) - \left(A_i \times SF_i\right)$$

$$\Delta S = \left(30 \cancel{acres} \times 5070.6 \frac{lb\ CO_2}{\cancel{acre} \cdot yr}\right) - \left(30 \cancel{acres} \times 1341.2 \frac{lb\ CO_2}{\cancel{acre} \cdot yr}\right)$$

$$\Delta S = 152{,}118 \frac{lb\ CO_2}{yr} - 40{,}236 \frac{lb\ CO_2}{yr}$$

$$\boxed{\Delta S = \mathbf{111{,}882}\ \frac{lb\ CO_2}{yr}}$$

### 10.4.2  Decrease in Sequestration (Forfeiture) Problem #2

A USAF Base is in Utah.  The Base has decided to clear 25 acres of forestland and convert this land to grassland.

**Step 1: Determine the region the land use change is occurring.**  Since the USAF Base is in Utah, it is in the Western Region.

**Step 2:  Select the appropriate sequestration factors from Table 10-1.**  For the Western Region, the sequestration factor for **forestland is 2355.4 lb CO₂/acre-year**.   The sequestration factor for **grassland is 523.4 lb CO₂/acre-year**.

**Step 3:  Use Equation 10-1 to determine the effect of converting the 25 acres of grassland into forestland.**

$$\Delta S = \left(A_f \times SF_f\right) - \left(A_i \times SF_i\right)$$

$$\Delta S = \left(25 \cancel{acres} \times 523.4 \frac{lb\ CO_2}{\cancel{acre} \cdot yr}\right) - \left(25 \cancel{acres} \times 2355.4 \frac{lb\ CO_2}{\cancel{acre} \cdot yr}\right)$$

$$\Delta S = 13{,}085 \frac{lb\ CO_2}{yr} - 58{,}885 \frac{lb\ CO_2}{yr}$$

$$\boxed{\Delta S = \mathbf{-45{,}800}\ \frac{lb\ CO_2}{yr}}$$

Converting 25 acres of forestland to grassland decreases the sequestration of carbon dioxide by 45,800 lb/year.

### 10.4.3  Decrease in Sequestration (Forfeiture) Problem #3

A USAF Base is in Utah.  The Base has decided to clear 25 acres of forestland and convert this land in to a 5-acre office building, a 15-acre parking lot, the remaining 5 acres would be grassed.

**Step 1: Determine the region the land use change is occurring.** A USAF Base is in Utah, which is in the Western Region.

**Step 2: Select the appropriate sequestration factors from Table 10-1**. For the Western Region, the sequestration factor for **forestland is 2355.4 lb $CO_2$/acre-year** and the sequestration factor for **grassland is 523.4 lb $CO_2$/acre-year**. The building and parking lot (20-acre total) are impervious surfaces; therefore, the sequestration factor for **impervious surfaces is 0.0 lb $CO_2$/acre-year**

**Step 3: Use Equation 10-1 to determine the effect of converting the 25 acres of grassland into forestland.**

$$\Delta S = \left( A_f \times SF_f \right) - \left( A_i \times SF_i \right)$$

$$\Delta S = \left[ \left( 5 acres \times 523.4 \frac{lb\ CO_2}{acre \cdot yr} \right) + \left( 20 acres \times 0.0 \frac{lb\ CO_2}{acre \cdot yr} \right) \right] - \left( 25 acres \times 2355.4 \frac{lb\ CO_2}{acre \cdot yr} \right)$$

$$\Delta S = 2{,}617 \frac{lb\ CO_2}{yr} - 58{,}885 \frac{lb\ CO_2}{yr}$$

$$\boxed{\Delta S = -56{,}268 \frac{lb\ CO_2}{yr}}$$

In other words, converting 25 acres of forestland to 20 acres of impervious surface and 5 acres of grassland in the Western Region results in a forfeiture of sequestration by 56,268 pounds of carbon dioxide per year.

## 10.5  References

Council on Environmental Quality. (2016). Final Guidance for Federal Departments and Agencies on Consideration of Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental Policy Act Reviews (81 FR 51866).

Zhu, Zhiliang, ed., Bouchard, Michelle, Butman, David, Hawbaker, Todd, Li, Zhengpeng, Liu, Jinxun, Liu, Shuguang, McDonald, Cory, Reker, Ryan, Sayler, Kristi, Sleeter, Benjamin, Sohl, Terry, Stackpoole, Sarah, Wein, Anne, and Zhu, Zhiliang, 2011, Baseline and projected future carbon storage and greenhouse-gas fluxes in the Great Plains region of the United States: U.S. Geological Survey Professional Paper 1787, 28 p. (Also available at http://pubs.usgs.gov/pp/1787/.)

Zhu, Zhiliang, and Reed, B.C., eds., 2012, Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1797, 192 p. (Also available at http://pubs.usgs.gov/pp/1797/.)

Zhu, Zhiliang, and Reed, B.C., eds., 2014, Baseline and projected future carbon storage and greenhouse-gas fluxes in ecosystems of the eastern United States: U.S. Geological Survey Professional Paper 1804, 204 p., http://dx.doi.org/10.3133/pp1804.

## 11.0  WILDFIRES (WILD)

➢ *Fugitive* Source

## 11.1  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/km$^2$ of $CO_2$ annually in the United States (Liu, Stanturf and Tian).  **Wildfires result in fugitive emissions of criteria pollutants and GHG.**

The size and intensity of a wildfire is affected by meteorological conditions, the species of vegetation involved, 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 11-1.



**Figure 11-1. Simplified Wildfire Control Volume**
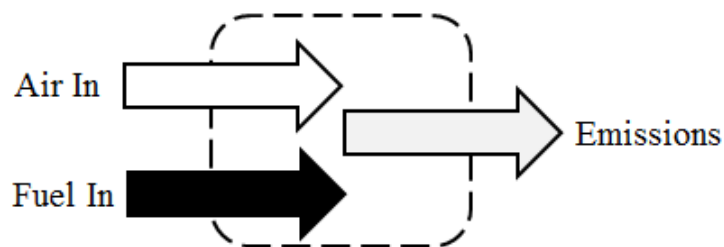
Most fuel loading figures are based on values for "available fuel," that is, combustible material consumed in a wildfire under specific weather conditions.  Each region of the country will have varying fuel load due to landscape and vegetation type.  The U.S. Forest Service (USFS) has developed a map of regions associated with wildfires.  These regions are shown in Table 11-1.

## Table 11-1. Estimated Average Fuel Loading Factor
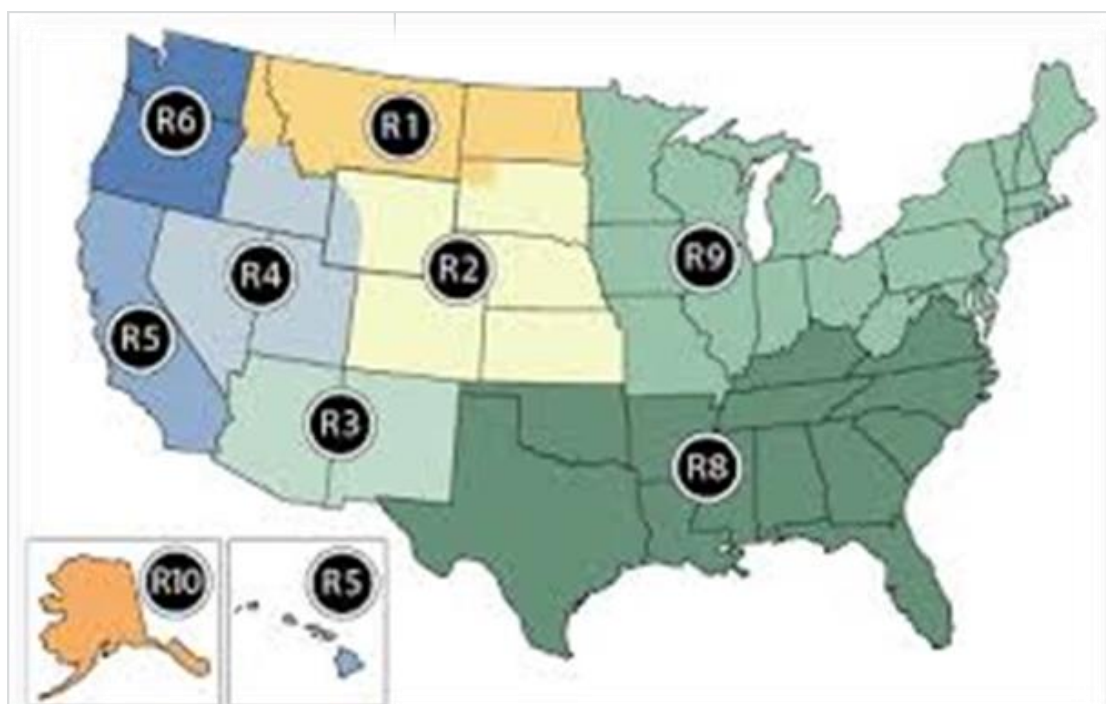


| National Region | States |
|---|---|
| Rocky Mountain | AZ, CO, ID, KS, MT, ND, NE, NM, NV, SD, UT, WA, WY |
| Region 1: Northern | Northern ID, MT, ND, Northwestern SD, Northeast WA |
| Region 2: Rocky Mountain | CO, KS, NE, parts of SD, parts of WY |
| Region 3: Southwestern | AZ, NM |
| Region 4: 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

## 11.2  Emission Factors

Estimating emissions from wildfires is difficult because the amount of pollution emitted into the atmosphere is likely based on the intensity and direction of the wildfire, which are influenced by several variables.  These variables include, but are not limited to, wind velocity, ambient temperature, relative humidity, and topography.  However, the most important factor in wildfire intensity is likely the fuel itself meaning the vegetation species and moisture content may have the greatest impact on combustion intensity.  The regions developed by the USFS have their own set of criteria pollutant EF.  These EFs were developed for each region based on the expected vegetation and fuel loading factor.  These EFs are provided in Table 11-2.

### Table 11-2. Criteria Pollutant Emission Factors for Wildfires

| Geographic Area | Emission Factor (ton/acre) | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | $NO_X$ | CO | $SO_X$ | Pb | VOC | $PM_{10}$ [a] | $PM_{2.5}$ [a] | $CO_2e$ [b] |
| 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

a.   Source document provides emission factor for total PM. The total PM conservatively assumed to be equal to $PM_{10}$ and $PM_{2.5}$

b.   $CO_2e$ emission factors are the sum of the product of $CO_2$, $CH_4$, and $N_2O$ 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

## 11.3  Emissions Calculations

Emissions from wildfires are calculated by multiplying the emission factor by the estimated area of land burned:

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

**Equation 11-1**

Where,

  **E(Pol)**  =  Annual emissions of pollutant (ton/yr)
  **A**     =  Area of land burned (Acres)
  **EF(Pol)** =  Emission factor (ton/acre)

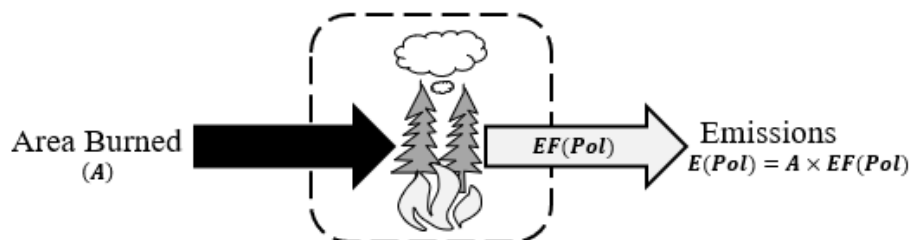A detailed control volume describing the calculation of emissions from wildfires is in Figure 11-2.



**Figure 11-2. Wildfire Control Volume**

## 11.4  Resources

As more data becomes available and emission models from wildfires become more accurate, it may be beneficial to utilize these models (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 USFS.

## 11.5  Example Problem

A Utah Air Force Base experienced a wildfire that consumed 18 acres of land.  Calculate the carbon monoxide (CO) and $PM_{10}$ emissions produced from the fire.

**Step 1 – Determine the region the Air Force Base lies within.**  The problem stated that the Air Force Base is in Utah.  According to Table 11-1, the Air Force Base is in **Region 4.**

**Step 2 – Select and record EFs.**  According to Table 11-2, the CO and $PM_{10}$ EFs in region 4 are **5.62E-01 and 6.83E-02 ton/acre** respectively.

**Step 3 – Calculate emissions.**  Using the EFs, the total area burned, and Equation 11-1, the CO and $PM_{10}$ emissions are calculated as follows:

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

For CO:

$$E(CO) = 18 \frac{Acre}{yr} \times 0.562 \frac{ton}{Acre}$$

$$\boxed{E(CO) = 10.12 \frac{ton}{yr}}$$

For PM10:

$$E(PM_{10}) = 18 \frac{Acre}{yr} \times 0.0683 \frac{ton}{Acre}$$

$$\boxed{E(PM_{10}) = 1.23 \frac{ton}{yr}}$$

## 11.6 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

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

## APPENDIX A - EPA HAP LIST

| CAS No. | Chemical/Compound |
|---|---|
| 75070 | Acetaldehyde |
| 60355 | Acetamide |
| 75058 | Acetonitrile |
| 98862 | Acetophenone |
| 53963 | 2-Acetylaminofluorene |
| 107028 | Acrolein |
| 79061 | Acrylamide |
| 79107 | Acrylic Acid |
| 107131 | Acrylonitrile |
| 107051 | Allyl Chloride |
| 92671 | 4-Aminobiphenyl |
| 62533 | Aniline |
| 90040 | o-Anisidine |
| 1332214 | Asbestos |
| 71432 | Benzene |
| 92875 | Benzidine |
| 98077 | Benzotrichloride |
| 100447 | Benzyl Chloride |
| 92524 | Biphenyl |
| 117817 | Bis(2-ethylhexyl)phthalate |
| 542881 | Bis(chloromethyl)ether |
| 75252 | Bromoform |
| 106990 | 1,3-Butadiene |
| 156627 | Calcium Cyanamide |
| 133062 | Captan |
| 63252 | Carbaryl |
| 75150 | Carbon Disulfide |
| 56235 | Carbon Tetrachloride |
| 463581 | Carbonyl Sulfide |
| 120809 | Catechol |
| 133904 | Chloramben |
| 57749 | Chlordane |
| 7782505 | Chlorine |
| 79118 | Chloroacetic Acid |
| 532274 | 2-Chloroacetophenone |
| 108907 | Chlorobenzene |
| 510156 | Chlorobenzilate |
| 67663 | Chloroform |
| 107302 | Chloromethyl methyl ether |
| 126998 | Chloroprene |
| 1319773 | Cresylic Acid |
| 95487 | o-Cresol |
| 108394 | m-Cresol |
| 106445 | p-Cresol |
| 98828 | Cumene |
| 94757 | 2,4-D |
| 3547044 | DDE |
| 334883 | Diazomethane |

| CAS No. | Chemical/Compound |
|---|---|
| 132649 | Dibenzofurans |
| 96128 | 1,2-Dibromo-3-chloropane |
| 84742 | Dibutylphthalate |
| 106467 | 1,4-Dichlorobenzene |
| 91941 | 3,3-Dichlorobenzidene |
| 111444 | Dichloroethyl ether |
| 542756 | 1,3-Dichloropropene |
| 62737 | Dichlorvos |
| 111422 | Diethanolamine |
| 121697 | N,N-Dimethylaniline |
| 64675 | Diethyl Sulfate |
| 119904 | 3,3-Dimethoxybenzidine |
| 60117 | Dimethyl Aminoazobenzene |
| 119937 | 3,3'-Dimethyl Benzidine |
| 79447 | Dimethyl Carbamoyl Chloride |
| 68122 | Dimethyl Formamide |
| 57147 | 1,1-Dimethyl Hydrazine |
| 131113 | Dimethyl Phthalate |
| 77781 | Dimethyl Sulfate |
| 534521 | 4,6-Dinitro-o-cresol |
| 51285 | 2,4-Dinitrophenol |
| 121142 | 2,4-Dinitrotoluene |
| 123911 | 1,4-Dioxane |
| 122667 | 1,2-Diphenylhydrazine |
| 106898 | Epichlorohydrin |
| 106887 | 1,2-Epoxybutane |
| 140885 | Ethyl Acrylate |
| 100414 | Ethyl Benzene |
| 51796 | Ethyl Carbamate |
| 75003 | Ethyl Chloride |
| 106934 | Ethylene Dibromide |
| 107062 | Ethylene Dichloride |
| 107211 | Ethylene Glycol |
| 151564 | Ethylene Imine |
| 75218 | Ethylene Oxide |
| 96457 | Ethylene Thiourea |
| 75343 | Ethylidene Dichloride |
| 50000 | Formaldehyde |
| 76448 | Heptachlor |
| 118741 | Hexachlorobenzene |
| 87683 | Hexachlorobutadiene |
| 77474 | Hexachlorocyclopentadiene |
| 67721 | Hexachloroethane |
| 822060 | Hexamethylene-1,6-diisocyanate |
| 680319 | Hexamethylphosphoramide |
| 110543 | Hexane |
| 302012 | Hydrazine |
| 7647010 | Hydrochloric Acid |

| CAS No. | Chemical/Compound |
|---|---|
| 7664393 | Hydrogen Fluoride |
| 123319 | Hydroquinone |
| 78591 | Isophorone |
| 58899 | Lindane |
| 108316 | Maleic Anhydride |
| 67561 | Methanol |
| 72435 | Methoxychlor |
| 74839 | Methyl Bromide |
| 74873 | Methyl Chloride |
| 71556 | Methyl Chloroform |
| 60344 | Methyl Hydrazine |
| 74884 | Methyl Iodide |
| 108101 | Methyl Isobutyl Ketone |
| 624839 | Methyl Isocyanate |
| 80626 | Methyl Methacrylate |
| 1634044 | Methyl tert Butyl Ether |
| 101144 | 4,4-Methylene bis(2-Chloroaniline) |
| 75092 | Methylene Chloride |
| 101688 | Methylene Diphenyl Diisocyanate |
| 101779 | 4,4'-Methylenedianiline |
| 91203 | Naphthalene |
| 98953 | Nitrobenzene |
| 92933 | 4-Nitrobiphenyl |
| 100027 | 4-Nitrophenol |
| 79469 | 2-Nitropropane |
| 684935 | N-Nitroso-N-Methylurea |
| 62759 | N-Nitrosodimethylamine |
| 59892 | N-Nitrosomorpholine |
| 56382 | Parathion |
| 82688 | Pentachloronitrobenzene |
| 87865 | Pentachlorophenol |
| 108952 | Phenol |
| 106503 | p-Phenylenediamine |
| 75445 | Phosgene |
| 7803512 | Phosphine |
| 7723140 | Phosphorus |
| 85449 | Phthalic Anhydride |
| 1336363 | Polychlorinated Biphenyls |
| 1120714 | 1,3-Propane Sultone |
| 57578 | beta-Propiolactone |
| 123386 | Propionaldehyde |
| 114261 | Propoxur |
| 78875 | Propylene Dichloride |
| 75569 | Propylene Oxide |
| 75558 | 1,2-Proplenimine |
| 91225 | Quinoline |
| 106514 | Quinone |
| 100425 | Styrene |

# APPENDIX A - EPA HAP LIST

| CAS No. | Chemical/Compound |
|---------|-------------------|
| 100425 | Styrene |
| 96093 | Styrene Oxide |
| 1746016 | 2,3,7,8-Tetrachlorodibenzo-p-dioxin |
| 79345 | 1,1,2,2-Tetrachloroethane |
| 127184 | Tetrachloroethylene |
| 7550450 | Titanium Tetrachloride |
| 108883 | Toluene |
| 95807 | 2,4-Toluene Diamine |
| 584849 | 2,4-Toluene Diisocyanate |
| 95534 | o-Toluidine |
| 8001352 | Toxaphene |
| 120821 | 1,2,4-Trichlorobenzene |
| 79005 | 1,1,2-Trichloroethane |
| 79016 | Trichloroethylene |
| 95954 | 2,4,5-Trichlorophenol |

| CAS No. | Chemical/Compound |
|---------|-------------------|
| 88062 | 2,4,6-Trichlorophenol |
| 121448 | Triethylamine |
| 1582098 | Trifluralin |
| 540841 | 2,2,4-Trimethylpentane |
| 108054 | Vinyl Acetate |
| 593602 | Vinyl Bromide |
| 75014 | Vinyl Chloride |
| 75354 | Vinylidene Chloride |
| 1330207 | Xylenes |
| 95476 | o-Xylene |
| 108383 | m-Xylene |
| 106423 | p-Xylene |
| --- | Antimony Compounds |
| --- | Arsenic Compounds |
| --- | Beryllium Compounds |

| CAS No. | Chemical/Compound |
|---------|-------------------|
| --- | Cadmium Compounds |
| --- | Chromium Compounds |
| --- | Cobalt Compounds |
| --- | Coke Oven Emissions |
| --- | Cyanide Compounds [1] |
| --- | Glycol Ethers [2] |
| --- | Lead Compounds |
| --- | Manganese Compounds |
| --- | Mercury Compounds |
| --- | Fine Mineral Fibers [3] |
| --- | Nickel Compounds |
| --- | Polycyclic Organic Matter [4] |
| --- | Radionuclides (including Radon) [5] |
| --- | Selenium Compounds |

1. X'CN where X=H' or any other group where a formal dissociation may occur. For example KCN or $Ca(CN)_2$.
2. Includes mono- and di-ethers of ethylene glycol, diethylene glycol, and triethylene glycol $R-(OCH_2CH_2)_n-OR'$, where:

    $n$ = 1, 2, or 3;

    R = alkyl C7 or less; or R = phenyl or alkyl substituted phenyl;

    R' = H or alkyl C7 or less; or OR' consisting of carboxylic acid ester, sulfate, phosphate, nitrate, or sulfonate.
3. Includes mineral fiber emissions from facilities manufacturing or processing glass, rock, or slag fibers (or other mineral derived fibers) of average diameter 1 micrometer or less.
4. Includes organic compounds with more than one benzene ring, and which have a boiling point greater than or equal to 100°C.
5. A type of atom which spontaneously undergoes radioactive decay.