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**AIR EMISSIONS GUIDE FOR AIR FORCE TRANSITORY
SOURCES**

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



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AIR EMISSIONS GUIDE FOR AIR FORCE TRANSITORY SOURCES

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 this document are true, accurate, and complete.

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293 **ACRONYMS**

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

295

296	AAFES	Army & Air Force Exchange Service
297	ACAM	Air Conformity Applicability Model
298	AFCEC	Air Force Civil Engineer Center
299	AFMAN	Air Force Manual
300	AGE	Aerospace Ground Equipment
301	ALAPCO	Association of Local Air Pollutant Control Officials
302	AMX	Aircraft Maintenance Squadron
303	APIMS	Air Program Information Management System
304	ARAR	Applicable or Relevant and Appropriate Requirements
305	BEE	Bioenvironmental Engineer
306	BOOS	Burners Out of Service
307	CAIR	Clean Air Interstate Rule
308	CALMIM	California Landfill Methane Inventory Model
309	CARB	California Air Resources Board
310	CAS	Chemical Abstracts Service
311	CERCLA	Comprehensive Environmental Response, Compensation, and Liability Act
312	CONUS	Continental United States
313	DAC	Defense Ammunition Center
314	DODIC	Department of Defense Identification Codes
315	ECOM	External Combustion Engine
316	EESOH-MIS	Enterprise Environmental, Safety and Occupational Health Management
317		Information System
318	EIAP	Environmental Impact Analysis Process
319	EPAct	Energy Policy Act
320	EPCRA	Emergency Planning and Community Right-to-Know Act
321	FESOP	Federally Enforceable State Operating Permit
322	FIRE	Factor Information Retrieval System
323	HAP	Hazardous Air Pollutant
324	HAZMART	Hazardous Materials Pharmacy
325	HEPA	High Efficiency Particulate Air
326	HVAC	Heating, Ventilating, and Air Conditioning
327	ICAO	International Civil Aviation Organization
328	ICOM	Internal Combustion Engine
329	LAER	Lowest Achievable Emissions Rate
330	LandGEM	Landfill Gas Emissions Model
331	MAJCOM	Major Command
332	MEM	Mass of Energetic Material

333	MIDAS	Munitions Items Disposition Action System
334	NAAQS	National Ambient Air Quality Standards
335	NAICS	North American Industry Classification System
336	NASA	National Aeronautics and Space Administration
337	NEPA	National Environmental Policy Act
338	NESHAP	National Emission Standards for Hazardous Air Pollutants
339	NEW	Net Explosive Weight
340	OCONUS	Outside Continental United States
341	OTAQ	Office of Transportation and Air Quality
342	PEMS	Predictive Emission Monitoring System
343	RCRA	Resource Conservation and Recovery Act
344	SAR	Second Assessment Report
345	SAW	Submerged Arc Welding
346	SIC	Standard Industrial Classification
347	SIP	State Implementation Plan
348	SMAW	Shielded Metal Arc Welding
349	SME	Subject Matter Expert
350	STAPPA	State and Territorial Air Pollution Program Administrators
351	TIM	Time in Mode
352	USAF	United States Air Force
353	VIN	Vehicle Identification Number
354		

355 **BREVITY CODES**

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

358

359	AB	Afterburner
360	AEI	Air Emissions Inventory
361	AERR	Air Emissions Reporting Requirements
362	AFB	Air Force Base
363	AFI	Air Force Instruction
364	AFPMB	Armed Forces Post Management Board
365	AFRL	Air Force Research Laboratory
366	APU	Auxiliary Power Unit
367	BFB	Bubbling Fluidized Bed
368	BMP	Best Management Practices
369	BSFC	Brake-Specific Fuel Consumption
370	CAA	Clean Air Act
371	CAAA	Clean Air Act Amendments (of 1990)
372	CE	Civil Engineering
373	CEMS	Continuous Emission Monitoring System
374	CEV	Civil Engineering Environmental
375	CFB	Circulating Fluidized Bed
376	CFC	Chlorofluorocarbon
377	CFR	Code of Federal Regulations
378	CI	Compression Ignition
379	CNG	Compressed Natural Gas
380	DLA	Defense Logistics Agency
381	DoD	Department of Defense
382	DOE	Department of Energy
383	EA	Environmental Assessment
384	EDMS	Emissions and Dispersion Modeling System
385	EF	Emission Factor
386	EGBE	Ethylene Glycol Butyl Ether
387	EIIP	Emissions Inventory Improvement Program
388	EIP	Emissions Inventory Plan
389	EIR	Emissions Inventory Report
390	EIS	Environmental Impact Statement
391	EOD	Explosive Ordnance Disposal
392	EPA	Environmental Protection Agency
393	ERP	Environmental Restoration Program
394	ESP	Electrostatic Precipitator

395	ESTCP	Environmental Security Technology Certification Program
396	FAA	Federal Aviation Administration
397	FBC	Fluidized Bed Combustor
398	FCAW	Flux-Cored Arc Welding
399	FF	Fabric Filter
400	FFR	Fuel Flow Rates
401	FFV	Flexible Fuel Vehicles
402	FGD	Flue Gas Desulphurization
403	FGR	Flue Gas Recirculation
404	GHG	Greenhouse Gas
405	GMAW	Gas Metal Arc Welding
406	GOV	Government Owned Vehicle
407	GSA	General Services Administration
408	GSE	Ground Support Equipment
409	GVW	Gross Vehicle Weight
410	GWP	Global Warming Potential
411	HBFC	Hydrobromofluorocarbon
412	HC	Hydrocarbon
413	HCFC	Hydrochlorofluorocarbon
414	HCP	Hard Chrome Plating
415	HEI	High Explosive Incendiary
416	HEV	Hybrid Electric Vehicles
417	HHV	High Heat Value
418	HMA	Hot Mix Asphalt
419	HVLP	High Volume Low Pressure
420	HVOF	High Velocity Oxy-Fuel
421	IC	Internal Combustion
422	IPCC	Intergovernmental Panel on Climate Change
423	IPCT	Industrial Process Cooling Towers
424	IRP	Installation Restoration Program
425	LDF	Liquid Drift Factors
426	LEL	Lower Explosive Limit
427	LFB	Low Flyby
428	LFP	Low Flight Pattern
429	LGRVM	Vehicle Management Flight Vehicle Maintenance
430	LNB	Low NO _x Burner
431	LPG	Liquefied Petroleum Gas
432	LTO	Landing and Takeoff
433	MEK	Methyl Ethyl Ketone
434	MM	Minutemen Missiles

435	MPF	Military Personnel Flight
436	MPO	Metropolitan Planning Office
437	MSW	Municipal Solid Waste
438	NACAA	National Association of Clean Air Agencies
439	NC	Nameplate Capacity
440	NDI	Non-Destructive Inspection
441	NEI	National Emission Inventory
442	NMHC	Non-Methane Hydrocarbons
443	NMOC	Non-Methane Organic Compounds
444	NMTOC	Non-Methane Total Organic Compounds
445	NSCR	Non-Selective Catalytic Reduction
446	NSPS	New Source Performance Standards
447	NSR	New Source Review
448	OBOD	Open Burning/Open Detonation
449	OBODM	Open Burning/Open Detonation Model
450	OCA	Off-Site Consequences Analysis
451	ODC	Ozone Depleting Chemicals
452	ODP	Ozone Depletion Potential
453	ODS	Ozone Depleting Substances
454	OIAI	Once In Always In
455	OLVIMS	On-line Vehicle Interactive Management System
456	P2	Pollution Prevention
457	PAH	Polycyclic Aromatic Hydrocarbon
458	PBT	Persistent Bioaccumulative and Toxic
459	PM	Particulate Matter – Aerodynamic diameter unspecified
460	PM ₁₀	Particulate Matter – Aerodynamic diameter < 10 micrometers
461	PM _{2.5}	Particulate Matter – Aerodynamic diameter < 2.5 micrometers
462	POL	Petroleum, Oil, and Lubricant
463	POTW	Publicly Owned Treatment Works
464	POV	Privately Owned Vehicles
465	PSD	Prevention of Significant Deterioration
466	PTE	Potential to Emit
467	RMP	Risk Management Plan
468	RVP	Reid Vapor Pressure
469	SCC	Source Classification Code
470	SDS	Safety Data Sheets
471	SCR	Selective Catalytic Reduction
472	SF	Spillage Factor
473	SI	Spark Ignition
474	SNCR	Selective Non-Catalytic Reduction

475	TCLP	Toxicity Characteristic Leaching Procedure
476	TDS	Total Dissolved Solids
477	TGO	Touch-and-Go
478	THC	Total Hydrocarbons
479	TLG	Total Landfill Gas
480	TNMOC	Total Non-Methane Organic Compounds
481	TO	Technical Order
482	TOC	Total Organic Compounds
483	TOG	Total Organic Gas
484	TRI	Toxic Release Inventory
485	TSD	Treatment, Storage, & Disposal
486	TSP	Total Suspended Particulate
487	ULSD	Ultra-Low Sulfur Diesel
488	US	United States
489	USDA	United States Department of Agriculture
490	UST	Underground Storage Tanks
491	UV	Ultraviolet
492	VKT	Vehicle Kilometers Traveled
493	VMIF	Vehicle Maintenance Index File
494	VMT	Vehicle Miles Traveled
495	VOC	Volatile Organic Compound
496		
497		
498		

499 **ABBREVIATIONS**

500 (Shortened form of a word or phrase)

501

502 μg Microgram(s)

503 A-hr Ampere-hours

504 A/ft^2 Ampere per square foot

505 Btu British Thermal Unit

506 $^{\circ}\text{C}$ Degrees Celsius

507 CH_4 Methane

508 CO Carbon Monoxide

509 CO_2 Carbon Dioxide

510 Co Cobalt

511 Cr Chromium

512 Cr^{+6} Hexavalent Chromium

513 Cr_2O_3 Chromium Oxide

514 EtO Ethylene Oxide

515 $^{\circ}\text{F}$ Degrees Fahrenheit

516 ft Foot (feet)

517 g Grams

518 g/L Grams per Liter

519 gal Gallon(s)

520 HCl Hydrochloric Acid

521 hp Horsepower

522 hr Hour(s)

523 kg Kilogram

524 kW Kilowatt(s)

525 L Liter

526 lb Pound(s)

527 Mg Megagram(s) [i.e., metric ton]

528 mg Milligram(s)

529 MMBtu Million British Thermal Units

530 Mn Manganese

531 NH_3 Ammonia

532 Ni Nickel

533 N_2O Nitrous Oxide

534 NO_2 Nitrogen Dioxide

535 NO_x Nitrogen Oxides

536 O_3 Ozone

537 Pb Lead

538 PERC Perchloroethylene

539	PFC	Perfluorocarbon
540	ppm	Parts per Million
541	ppmv	Parts per Million by Volume
542	ppmw	Parts per Million by Weight
543	psi	Pounds per Square Inch
544	psia	Pounds per Square Inch Absolute
545	°R	Degrees Rankine
546	scf	Standard Cubic Feet
547	SF ₆	Sulfur Hexafluoride
548	SO ₂	Sulfur Dioxide
549	SO _x	Sulfur Oxides
550	TNT	Trinitrotoluene
551	tpy	Tons per Year
552	yr	Year (s)
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558 1 INTRODUCTION

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560 1.1 Background and Purpose

561 In 1970, the United States Environmental Protection Agency (EPA) established the Federal law
562 known as the Clean Air Act (CAA) to better control hazardous air emissions and reduce the
563 amount of harmful pollutants expelled into the air. The US EPA is responsible for protecting
564 the public and the environment by establishing standards such as the CAA aimed at reducing
565 pollutant emissions. Additionally, the EPA also established the National Ambient Air Quality
566 Standards (NAAQS) that require facility managers to always be aware of their facility's
567 compliance status with Federal air quality regulations.

568

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

577

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

584

585

586 1.2 Transitory Sources

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

594

595 Transitory sources are non-routine and/or seasonal sources (may be stationary, mobile, or
596 neither) that are short-term in nature. Historically, transitory sources have been erroneously

597 included as stationary or mobile sources in AElS. Transitory source emissions should generally
598 only be accounted for in evaluating potential air quality impacts of proposed actions under the
599 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA),
600 National Environmental Policy Act (NEPA), and General Conformity.

601
602 This Guide addresses transitory emissions sources typically found on USAF installations.
603 Sources of emissions may be further subdivided as:

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

612
613 Since only point and fugitive source emissions are applicable to USAF installations because of
614 their direct bearing on the determination of major source status, biogenic sources are not
615 addressed within this Guide.

616

617 **1.2.1 Non-routine Sources**

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

625

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

629

630 **1.2.2 Seasonal Sources**

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

635
636 Seasonal mobile sources are those that are non-stationary and include both “on-road” and “off-
637 road” engines and equipment. Data for mobile sources are based on engine size, vehicle
638 weight, equipment type, and/or horsepower. On-road vehicles include automobiles used for
639 the transport of passengers or freight. Nonroad sources include a multitude of equipment used
640 for construction, agriculture, recreation, and many other similar purposes.

641
642 *Seasonal sources should only be considered stationary sources if they are fixed at one*
643 *location on a permanent basis for at least two (2) years and operated at that single location*
644 *for three (3) or more months each year.*

645 646 **1.3 Pollutants**

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

651 **1.3.1 Criteria Pollutants**

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

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

- 658 • PM includes the very-fine dust, soot, smoke, and droplets formed from chemical
659 reactions and incomplete burning of fuels.
- 660 • The fine particles of PM can get deep into the lungs, causing increased respiratory
661 illnesses and tens of thousands of deaths each year.
- 662 • PM is defined as any particle with an equivalent diameter of less than or equal to 10
663 microns (**PM₁₀**) and is further subdivided to include a separate standard for particles
664 with an equivalent aerodynamic diameter of less than or equal to 2.5 microns (**PM_{2.5}**).

666 **Ground-Level Ozone (O₃):**

- 667 • O₃ is a primary component of smog that causes human health problems and damage to
668 forests and agricultural crops.
- 669 • Repeated exposure to O₃ can make people more susceptible to respiratory infections
670 and lung inflammation.
- 671 • Though there is a NAAQS, **O₃ is not emitted directly into the air.**

- 672 • Two types of compounds that are the main ingredients (precursors) in forming ground-
673 level O₃ in the presence of ultraviolet (UV) light include:
- 674 ○ **Volatile Organic Compounds (VOCs):** Defined as “any compound of carbon,
675 excluding carbon monoxide (CO), carbon dioxide (CO₂), carbonic acid,
676 metallic carbides or carbonates, and ammonium carbonate, which participates
677 in atmospheric photochemical reactions” (40 CFR 51.100). Note that 40 CFR
678 51.100 also exempts compounds based on their negligible photochemical
679 reactivity. Examples of these exempt compounds include methane, ethane,
680 acetone, et al. Common sources of VOCs include gas and diesel-fueled
681 automobiles, fuel storage containers, and solvents used in paints and
682 degreasers.
- 683 ○ **Nitrogen oxides (NO_x):** Provides the reddish-brown tint in smog. These are
684 produced from the burning of gasoline, coal, or oil.
685

686 **Carbon Monoxide (CO):**

- 687 • CO is produced when fossil fuel burns incompletely because of insufficient oxygen
688 (O₂).
- 689 • Wood, coal, and charcoal fires and gasoline engines always produce CO.
- 690 • In the United States, particularly in urban areas, most CO air emissions are from mobile
691 sources.
- 692 • CO can cause harmful health effects by reducing O₂ delivery to the body’s organs (like
693 the heart and brain) and tissues.
694

695 **Sulfur Oxides (SO_x):**

- 696 • Sulfur Oxides are a group of molecules made of sulfur and oxygen atoms, such as
697 Sulfur Dioxide (SO₂), and Sulfur Trioxide (SO₃).
- 698 • Since SO₂ is the most common form of the sulfur oxides, the EPA uses it as an
699 indicator for the larger group of SO_x.
- 700 • SO₂ in the ambient air is just one of several sulfur oxides that contribute to air quality
701 issues.
- 702 • SO_x emissions are produced from fossil fuel combustion at power plants (73 percent)
703 and other industrial facilities (20 percent)
- 704 • SO_x is linked to several adverse effects on the respiratory system.

705 **Nitrogen Oxides (NO_x):**

- 706 • Nitric Oxide (NO), Nitrogen Dioxide (NO₂), and nitrate radicals (NO₃) are collectively
707 called Nitrogen Oxides (NO_x)
- 708 • NO₂ is a subgroup of nitrogen oxides and is the most environmentally concerning
709 component. It also acts as an indicator for the presence of the larger group of NO_x.
- 710 • NO_x forms quickly from vehicle, power plant, and off-road equipment emissions.
- 711 • NO_x contributes to the formation of ground-level O₃ and fine particle pollution.
- 712 • NO_x causes airway inflammation and can increase breathing problems for people with
713 compromised respiratory systems (e.g., asthma).
- 714

715 **Lead (Pb):**

- 716 • Pb is a metal found naturally in the environment as well as in manufactured products.
- 717 • Prior to 1980, the major sources of Pb were on-road vehicles. As a result, the EPA
718 removed Pb from motor vehicle gasoline, resulting in a 95% decline in Pb emissions
719 between 1980 and 1999.
- 720 • Today, the major sources of Pb are ore and metals processing (e.g., lead smelters).
- 721 • Depending on the level of exposure, Pb can adversely affect the nervous system, kidney
722 function, immune system, reproductive and developmental systems, and the
723 cardiovascular system.
- 724

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

730

731 Also, note that O₃ is not directly emitted into the air, but is created through photochemical
732 reactions involving NO_x and VOCs, and PM may be the result of the release of primary
733 pollutants or the formation of secondary pollutants. Therefore, this Guide provides EFs for a
734 list of criteria pollutants which differ slightly from those regulated by the NAAQS. The list of
735 “criteria pollutants” for emissions inventory purposes are reported as those shown below:

- 736 • CO
- 737 • NO_x
- 738 • PM₁₀
- 739 • PM_{2.5}
- 740 • SO_x
- 741 • VOCs

742 • Pb

743

744 1.3.2 Hazardous Air Pollutants (HAPs)

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

756

757 1.3.3 Greenhouse Gases (GHGs)

758 Global climate change is becoming one of the most important issues of the 21st century. Some
759 GHGs, such as CO₂, are emitted to the atmosphere through both naturally occurring processes
760 as well as human activities. Other GHGs (e.g., fluorinated gases) are created and emitted
761 solely through human activities. The principal GHGs emitted to the atmosphere through
762 human actions are CO₂, methane (CH₄), nitrous oxide (N₂O), and fluorinated gases.

763

764 CO₂ is the primary GHG emitted through human activity, accounting for 82 percent of all GHG
765 emissions from human actions in the United States. CO₂ enters the atmosphere primarily
766 through the burning of fossil fuels and industrial processes. CO₂ is also removed from the
767 atmosphere (or “sequestered”) when it is absorbed by plants and the ocean as part of the global
768 carbon cycle. CH₄ is emitted during the production and transport of coal, natural gas, and oil.
769 CH₄ emissions also result from livestock and other agricultural practices and by the decay of
770 organic waste in municipal solid waste landfills. N₂O is emitted during agricultural and
771 industrial processes, as well as during combustion of fossil fuels and solid waste.

772

773 GHGs are assigned a Global Warming Potential (GWP), which is a measure of how much heat
774 the gas traps in the atmosphere calculated over a specific time interval, typically 100 years.

775 The higher the GWP, the greater the potential for the gas to trap heat, and the more harmful the
776 gas is regarded. CO₂ is used as the baseline gas and assigned a GWP of 1. GHG emissions are
777 converted into equivalent CO₂ (CO₂e) by taking the product of the emissions of each GHG and
778 its respective GWP. Table A-1 of 40 CFR 98 provides the GWPs for several GHGs. The
779 GWP values given throughout this Guide are subject to change in the upcoming years due to
780 new data becoming available but are considered current as of June 2021. The total GHG

781 emissions are calculated by summing all emissions from each gas and is generally derived from
 782 the following equation:

$$783 \quad E(\text{CO}_2e) = \sum_{i=1}^n [E(\text{GHG})_i \times \text{GWP}(\text{GHG})_i]$$

784 **Equation 1-1**

785 Where,

786 **E(CO₂e)** = Greenhouse gas emissions expressed as CO₂ equivalent (CO₂e)

787 **E(GHG)_i** = Emissions of individual GHG species i

788 **GWP(GHG)_i** = Global warming potential for GHG species, i

789 **i** = GHG species, most commonly CO₂, CH₄, and N₂O

790

791

792 **1.4 Applicable Air Quality Related Regulations**

793 **1.4.1 CAA Titles**

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

800

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

- 811 • 10 tpy or more of any HAP **or** 25 tpy or more of any combination of HAPs
- 812 • 100 tpy or more of any air pollutant subject to regulation. For some of the criteria
 813 pollutants, lower thresholds exist for certain nonattainment areas including:
 - 814 ○ 50 tpy of VOC and NO_x emissions in “serious” O₃ nonattainment areas and in
 815 O₃ transport regions.
 - 816 ○ 25 tpy of VOC and NO_x emissions in “severe” O₃ nonattainment areas.
 - 817 ○ 10 tpy of VOC and NO_x emissions in “extreme” O₃ nonattainment areas.

- 818 ○ 50 tpy of CO emissions in “serious” CO nonattainment areas.
- 819 ○ 70 tpy of PM₁₀ emissions in “serious” PM₁₀ nonattainment areas.

820 **1.4.1.1 New Source Review (NSR)**

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

828
829 PSD permits are required for new major sources or major modifications at existing sources in
830 attainment areas. The PSD program requires that any new construction or modification must
831 use the Best Available Control Technology (BACT) and perform air quality and environmental
832 impact analysis. There are 28 source categories given in 40 CFR 51.166 which, if they emit
833 100 tpy, **including fugitive emissions**, are regarded as PSD major sources. Sources that do not
834 fall into one of the 28 categories are regarded as PSD major sources if they emit 250 tpy,
835 **excluding fugitive emissions**. Generally, there are only three sources that fall into one of
836 these categories that may potentially be found on a USAF installation. These sources are fossil
837 fuel boilers (or combination thereof) totaling more than 250 Million British Thermal Units per
838 hour (MMBtu/hr) heat input; petroleum storage units with a capacity exceeding 300,000
839 barrels (9.45 million gallons); and any other stationary source category which, as of August 7,
840 1980, is being regulated under section 111 or 112 of the Act. The local air pollution control
841 agency may provide additional information regarding the PSD permit application process,
842 required for PSD major sources, as well as the typical length of time it takes before a permit is
843 issued.

844
845 Nonattainment NSR permits are required for new major sources or major modifications at
846 existing sources located in nonattainment areas. All nonattainment NSR programs require the
847 installation of the Lowest Achievable Emission Rate (LAER). LAER is determined either by
848 taking the most stringent emission limitation contained in a SIP for the category source or the
849 most stringent emission limit achieved in practice by such class or category of source,
850 whichever is more constraining. Additionally, since the construction is to take place in a
851 nonattainment area, part of the nonattainment NSR program requires some form of emission
852 offsets. These offsets are reductions in emissions from existing sources near the proposed
853 construction that are greater than the emissions increase from the new source to provide a net
854 air quality benefit.

855
856 Minor NSR permits are required for new construction that does not require PSD or
857 nonattainment NSR permits. These permits contain requirements limiting the emissions to

858 avoid PSD and nonattainment NSR, and to prevent the new construction from violating the
859 control strategy in a nonattainment area.

860

861 **1.4.1.2 General Conformity**

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

874

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

879

880 **1.4.2 National Environmental Policy Act (NEPA)**

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

- 884 • **Categorical Exclusion Determination** - A Categorical Exclusion Determination is a
885 proposed action that may be categorically excluded from a detailed environmental
886 analysis if the action meets certain criteria that a previous agency has previously
887 determined to have no significant environmental impact.
- 888 • **Environmental Assessment (EA)** – An Environmental Assessment is a proposed
889 action not categorically excluded and must be evaluated to determine if its undertaking
890 would significantly affect the environment. If there is no significant affect, the agency
891 issues a Finding of No Significant Impact (FONSI). If the EA concludes the action
892 results in a significant environmental impact, an Environmental Impact Statement must
893 be prepared.
- 894 • **Environmental Impact Statement (EIS)** – An Environmental Impact Statement (EIS)
895 is a detailed evaluation of the proposed action and its alternatives. A draft EIS is filed

896 with the EPA and the EPA publishes a “Notice of Availability” in the Federal Register.
897 Publication of the “Notice of Availability” begins a 45-day public comment period and
898 mandatory 30-day waiting period before the agency can decide on the proposed action.
899

900 **1.4.3 Environmental Impact Analysis Process (EIAP)**

901 The Environmental Impact Analysis Process (EIAP) is the Air Force’s tool for implementing
902 procedures for environmental impact analysis within the United States and abroad. Within the
903 United States, EIAP maintains compliance with NEPA and the Council on Environmental
904 Quality (CEQ) Regulations for Implementing the Procedural Provisions of the NEPA (40 CFR
905 Parts 1500 through 1508). USAF environmental impact analyses of actions outside the United
906 States are to be in accordance with Executive Order (EO) 12114, Environmental Effects
907 Abroad of Major Federal Actions and 32 CFR 187, Environmental Effects Abroad of Major
908 Department of Defense Actions.
909

910 **1.5 Authoritative Algorithms and Emission Factors (EFs)**

911 An EF is a representative value that attempts to relate the quantity of a pollutant released with
912 the activity associated with the release of that pollutant. These factors are usually expressed as
913 the weight of pollutant released per a unit weight, volume, distance, or duration of the pollutant
914 emitting activity. In most cases, these factors are simply averages of all available data of
915 acceptable quality and are generally assumed to be representative of long-term averages for all
916 facilities in the source category.
917

918 This Guide is the USAF single authoritative compilation of algorithms and EFs for transitory
919 sources. No other algorithms or EFs shall be used unless mandated by a legally enforceable
920 regulatory requirement (e.g., permit stipulation) or approved by AFCEC/CZTQ on a case-by-
921 case basis. Algorithms and EFs used by the USAF are generally from the *Compilation of Air*
922 *Pollutant Emission Factors* (AP-42) and WebFIRE (EPA’s online EF database). However,
923 data in AP-42 is often obsolete due to equipment updates that occur more frequently than EF
924 research and WebFIRE is known to contain errors and conflicting data. Additionally, EFs for
925 Air Force-unique circumstances and sources have been developed by the USAF and are only
926 available in this, the Stationary, and Mobile Source Guides. Therefore, the only algorithms and
927 EFs authorized for use in estimating USAF air emissions are those maintained within this and
928 other official USAF source guides, unless a specific temporary exemption is approved by
929 AFCEC/CZTQ.
930

931 APIMS is the Air Force-approved information system for air quality, which provides a
932 standardized, integrated tool and methodology to track, manage, and report all data related to
933 the Air Quality Program. In accordance with AFMAN 32-7002, APIMS is mandated for use in
934 air quality permit management, air emission inventory, vehicle inspection & maintenance

935 certification, and air emissions reporting. The Installation/Base Civil Engineer –
936 Environmental Element must ensure the air quality compliance and resource management data
937 are accurately maintained in APIMS in a timely manner.

938
939 APIMS is mandated by AFMAN 32-7002 for estimating USAF AEI. This Guide is the single
940 authoritative compilation of algorithms and EFs, however, APIMS is periodically updated so
941 that the EFs and algorithms agree with the current source guide. All algorithms and EFs within
942 APIMS must be from within this and other official USAF source guides (unless specifically
943 approved by AFCEC/CZTQ). Upon discovery of any unauthorized algorithms and/or EFs
944 within APIMS, contact the APIMS Help Desk for removal or pursuing temporary authorization
945 from AFCEC/CZTQ.

946

947 **1.6 Emissions Inventory Methodologies**

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

- 957 • Emissions monitoring/sampling (e.g., continuous emissions monitoring or stack
958 sampling)
- 959 • Mass balances
- 960 • Source category emissions model
- 961 • State/industry factors
- 962 • Emission factors
- 963 • Engineering estimates

964

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

974 methods presented in this Guide use either EF estimates, material balance calculations, or
975 available modeling software, they are not meant to suggest these are the only alternatives
976 available.

977
978 Many EFs found in this Guide were taken directly from AP-42 where they were assigned a data
979 quality rating from “A” through “E”, with “A” being the best quality. The factor’s rating is a
980 general indication of the reliability of that factor based on the quality of the test and how well
981 the factor represents the emission source. Additional or alternative EFs may be available from
982 other sources, most notably the California Air Resource Board (CARB). If an EF for a specific
983 pollutant or process is not available, that does not mean the EPA believes the source should not
984 be inventoried, but that there is insufficient data to provide guidance.

985
986 AFMAN 32-7002 states that AEIs should be prepared and updated via APIMS. The default
987 EFs in APIMS are those found in this Guide. However, alternative EFs, such as those
988 requested by state and local air regulators, may be used if the alternative EF is submitted and
989 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

990
991 Where,

992 **E** = Total Emissions Released
993 **A** = Activity Rate
994 **EF** = Emission Factor
995 **ER** = Overall Emission Reduction Efficiency (%)
996

997
998 The overall emission reduction efficiency is the product of the control device destruction or
999 removal efficiency and the capture efficiency of the control system. When estimating
1000 emissions for an extended period, an average efficiency is used to account for routine
1001 operations. In some cases, a material balance approach may provide a better estimate of
1002 emissions than emission tests. In general, material balances are appropriate for use in
1003 situations where a high percentage of material is lost to the atmosphere. All the materials
1004 going into and coming out of the process must be considered to allow an emission estimation to
1005 be credible.

1006 1007 **1.7 Guide Organization**

1008 This Guide is organized into chapters that are specifically related to facilities or processes
1009 typically found at Air Force installations. Chapter topics may or may not correspond directly
1010 to source types identified in EPA, state, or local guidance documents. The intent is to consider
1011 sources usually associated with a facility/activity/process. This Guide specifically addresses

1012 transitory sources of air emissions. Guidance for addressing mobile or stationary sources of air
1013 pollutants may be found in the latest versions of the *Air Emissions Guide for Air Force Mobile*
1014 *Sources* or *Air Emissions Guide for Air Force Stationary Sources*, respectively.
1015

1016 1.8 References

- 1017 40 CFR 50, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
1018 Agency Subchapter C-Air Programs, Part 50-National Primary and Secondary Ambient Air
1019 Quality Standards,” U.S. Environmental Protection Agency
- 1020 40 CFR 51, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
1021 Agency Subchapter C-Air Programs, Part 51-Requirements for Preparation, Adoption, an
1022 Submittal of Implementation Plans,” U.S. Environmental Protection Agency
- 1023 40 CFR 93, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
1024 Agency Subchapter C-Air Programs, Part 93-Determining Conformity of Federal Actions to
1025 State or Federal Implementation Plans,” U.S. Environmental Protection Agency
- 1026 40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
1027 Agency Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting,” U.S.
1028 Environmental Protection Agency
- 1029 40 CFR Chapter V, “Title 40-Protection of the Environment, Chapter V-Council on
1030 Environmental Quality,” U.S. Environmental Protection Agency

1031

1032
1033

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1034 **2 BULK STORAGE TANK CLEANING (TCRL)**

1035 ➤ *Fugitive Source*

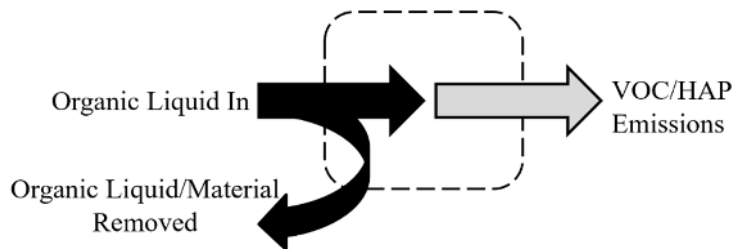
1036

1037 **2.1 Introduction**

1038 Storage tanks located on Air Force installations are used for storing materials, which
 1039 commonly include fuels such as JP-8, Jet A, MOGAS, and diesel, or even asphalt solvents.
 1040 These compounds are composed of VOCs and HAPs, which are released into the atmosphere
 1041 as the liquid evaporates. The storage tanks may contain anywhere from a few hundred to over
 1042 a million gallons and may be located above ground or underground. According to the EPA, an
 1043 underground storage tank (UST) is defined as a tank and any underground piping system that
 1044 has 10% or more of its combined volume underground. Liquid storage tanks that have more
 1045 than 90% of their volume above the ground surface are classified as above ground storage
 1046 tanks (AST). Various types of tanks can be used for storage, but the most common types found
 1047 on an AF installation are tanks with a roof that is either a self-supporting fixed roof or an
 1048 external floating roof type. Other tank types include internal floating roof and column-
 1049 supported fixed roof tanks.

1050

1051 All storage tanks are occasionally emptied and cleaned for activities such as service changes,
 1052 maintenance, and inspections. Cleaning bulk storage tanks is considered a non-routine source
 1053 because it is infrequently conducted. Emissions result from vapor displacement, the
 1054 evaporation of any clinging liquid within the tank, and from the evaporation of VOCs
 1055 contained within the remaining sludge. Most wet sludge is composed of about 80% to 90%
 1056 liquid by weight (USEPA 2012). For emissions calculations, the sludge may be conservatively
 1057 assumed to be 80% liquid by weight, with the remaining 20% composed of VOCs that are
 1058 entirely emitted to the atmosphere. **Bulk storage tank cleaning operations result in fugitive**
 1059 **emissions of VOCs and HAPs.** A graphic representation of emissions from bulk storage tank
 1060 cleaning operations is given in Figure 2-1.



1061

1062 **Figure 2-1. Simplified Bulk Storage Tank Cleaning Control Volume**

1063 There are several types of roof designs for storage tanks that determine the amount of
 1064 emissions released from tank use, though have no effect on the amount of emissions released
 1065 during tank cleaning. For more data on storage tanks and their emissions, refer to the “Storage

1066 Tanks” chapter of the latest version of the *Air Emissions Guide for Air Force Stationary*
1067 *Sources*.

1068

1069 The process of cleaning a storage tank may involve the following steps:

- 1070 • The liquid in the storage tank may first be tested for contamination.
- 1071 • Liquid from the tank is removed and placed in a vacuum truck.
- 1072 • Vapor space is de-gassed.
- 1073 • Remaining liquid/sludge is removed. This may involve the addition of distillates to
1074 flush the tank.
- 1075 • If needed, the tank may be ventilated to allow for safe entry for manual inspection.
- 1076 • Liquid is filtered out of the vacuum truck and back into the tank.
- 1077 • The filtered liquid is re-tested and chemical corrections are made, as needed.

1078

1079 Emissions from the cleaning of storage tanks are the result of tank degassing and cleaning,
1080 which includes sludge handling and degreasing. The process of emptying and refilling a tank
1081 is known as a tank turnover.

1082

1083 **2.2 NESHAP Applicability**

1084 There are several NESHAPs applicable to storage tanks provided in 40 CFR 63 Subparts OO,
1085 WW, EEEE, and CCCCC. These standards detail the requirements for the operation of
1086 storage tanks and any control devices that may be required during their use including
1087 applicability and compliance with work practice standards. Refer to the applicable subpart for
1088 detailed information regarding the frequency and work practice standards for degassing,
1089 maintenance, inspection, and cleaning of storage tanks.

1090

1091 **2.3 Control Techniques**

1092 There are several control techniques available for the capture and breakdown of VOCs and
1093 HAPs from storage tanks prior to their release into the atmosphere. During the process of
1094 degassing, the vapor from the storage tanks may flow through a carbon adsorption system,
1095 liquid scrubber, thermal oxidizer, or refrigerated vapor recovery system. In a carbon
1096 adsorption system, VOCs and HAPs are removed as the highly porous carbon works as a filter
1097 in the gas stream. Liquid scrubbers work by dissolving pollutants in liquid droplets and
1098 removing them from the inlet gas stream. Thermal oxidizers work by introducing the inlet
1099 stream to a burner where, after an extended residence time, the VOCs within the stream are
1100 thermally destroyed. Refrigerated vapor recovery systems pass the VOC saturated inlet stream
1101 through a series of condensers, converting the contaminants into liquid. The liquid is sent to a

1102 holding tank awaiting disposal. This type of control technique can recover up to 99% of the
1103 VOCs from the inlet gas stream.

1104

1105 **2.4 Emissions Calculation**

1106 Air pollutant emissions associated with bulk storage tank cleaning result from the vaporization
1107 of the organic liquid stored in the tank as well as the vaporization of any added distillates.
1108 When conducting a storage tank cleaning, the stock liquid is pumped out of the tank to empty it
1109 of its contents. Any emissions generated during this normal pump out, and the following idle
1110 period, if any, are accounted for as routine emissions and not calculated as specific to the tank
1111 cleaning process. Rather, the emissions specific to the tank cleaning process are the result of
1112 the purging of the tank's vapor space and the subsequent period of forced ventilation. The
1113 following equations primarily come from chapter 7 of AP-42, though some conservative
1114 assumptions have been made for simplification. The total emissions generated from bulk
1115 storage tank cleaning are estimated as follows.

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

Equation 2-1

1116

1117

1118 Where,

1119 L_{FV} = Total emissions due to forced ventilation (lb)

1120 L_P = Vapor space purge emissions associated with the first air change following the
1121 commencement of forced ventilation (lb)

1122 L_{CV} = Emissions from the continued forced ventilation following the first air change (lb)

1123

1124 **2.4.1 Vapor Space Purge Emissions**

1125 After the stock liquid is pumped from the tank, eductors, fans, or blowers are activated to
1126 remove the vapors remaining in the vapor space. This process marks the start of forced
1127 ventilation. This air change is referred to as the vapor space purge and the resultant emissions
1128 may be estimated as follows.

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

Equation 2-2

1129

1130

1131 Where,

1132 P_{VA} = True vapor pressure of the exposed volatile material in the tank (psia). This is
1133 provided in Table 2-1.

1134 V_V = Volume of the vapor space (ft³).

1135 R = Ideal gas constant, **10.731** (psia • ft³ / lb-mol • °R)

1136 T_V = Average temperature of the vapor space (°R)

1137 M_V = Stock vapor molecular weight (lb/lb-mol). This is provided in Table 2-1.

1138 S = Saturation factor. **A value of 0.5 may be used.**

1139 CE = Control efficiency of the control device used, if applicable

1140

1141 Note that the average vapor space temperature (T_V) is measured in degrees Rankine ($^{\circ}R$). To
 1142 convert from degrees Fahrenheit ($^{\circ}F$) to degrees Rankine ($^{\circ}R$), use the following equation:

1143
$$T_V(^{\circ}R) = T_V(^{\circ}F) + 459.67$$

1144 **Table 2-1. Properties of Various Fuels**

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

1145 SOURCE (unless otherwise stated): TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005.

1146 a. SOURCE: Section 7.1- "Organic Liquid Storage Tanks," Compilation of Air Pollutant Emission Factors - Volume I:
 1147 Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, November 2006.

1148 b. SOURCE: "JP-8 Volatility Study," Southwest Research Institute, March 2001. Vapor pressures calculated using the
 1149 composite data calculation, an average flash point temperature of 118.238°F, and atmospheric pressure of 760mmHg.
 1150 Flash point temperature average provided by "Petroleum Quality Information System Fuels Data (2005)," Defense
 1151 Logistics Agency, Defense Energy Support Center, Technology and Standardization Division, 2006.
 1152

1153

1154 Calculation of the vapor space volume is different for fixed roof versus floating roof tanks,
 1155 since the vapor space volume for a fixed roof also includes the volume of space above the
 1156 cylindrical shell of the tank and below the cone or dome-shaped roof. Assuming the storage
 1157 tank is cylindrical, the vapor space volume may be calculated using the following equation.

1158
$$V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

1159 **Equation 2-3**

1160 Where,

1161 **D** = Tank diameter (ft)

1162 **H** = Vapor space height (ft). For fixed roofs, this is the difference between the tank
 1163 shell height and the liquid height and sludge. For floating roofs, this is the
 1164 vapor space under the floating roof.

1165 **H_{RO}** = Roof outage (ft). For floating roof tanks, this value is 0. For fixed roof tanks,
 1166 this value is calculated differently depending on the roof geometry. See
 1167 Equation 2-4 or Equation 2-5 for calculation.

1168

1169 For a cone roof, the roof outage is calculated as follows.

$$1170 \quad H_{RO} = \frac{1}{6} \times S_R \times D$$

1171 **Equation 2-4**

1172 Where,

1173 **S_R** = Roof slope (ft/ft). A standard value of 0.0625 may be used if unknown.

1174

1175 For a dome roof, the outage is calculated as follows.

$$1176 \quad H_{RO} = \left(R_R - \sqrt{R_R^2 - R_S^2} \right) \times \left[\frac{1}{2} + \frac{1}{6} \times \left[\frac{\left(R_R - \sqrt{R_R^2 - R_S^2} \right)^2}{R_S} \right] \right]$$

1177 **Equation 2-5**

1178 Where

1179 **R_R** = Tank dome roof radius (ft)

1180

1181 **2.4.1.1 Calculation of Vapor Space Purge Emissions After Distillate Flushing**

1182 When the storage tank has been drained and the vapor space has been initially purged, the tank
 1183 may be flushed using a light distillate to aid in the removal of accumulated sludge. After this
 1184 distillate flushing, the vapor space is once again purged, though the values of P_{VA} and M_V used
 1185 in Equation 2-2 will have changed from the initial values of the stock liquid because the
 1186 remaining liquid is now a mixture of the stock and distillate. In the instance where distillate (or
 1187 any other solvent) is applied to remove sludge during tank cleaning, take the following steps to
 1188 correct the vapor pressure of the remaining mixture to estimate emissions resulting from this
 1189 second vapor space purge:

1190

1191 **Step 1 – Calculate the volume of each component in the mixture.** First, estimate the depth
 1192 of the liquid heel of the stock liquid and the depth of the applied distillate. Using this depth
 1193 and the interior dimensions of the tank, calculate the volume of each liquid as follows.

1194
$$V_i = h_i \times \frac{\pi \times D^2}{4}$$

1195 **Equation 2-6**

1196 Where,

1197 V_i = Volume of stock liquid or distillate (ft³)

1198 h_i = Depth of stock liquid or distillate (ft)

1199 D = Diameter of the tank (ft)

1200

1201 **Step 2 – Calculate the mass of each component in the mixture.** Using the volume
1202 calculated in the previous step, calculate the mass of each liquid by taking the product of their
1203 volumes and their respective densities.

1204
$$M_i = V_i \times \rho_i \times 7.48$$

1205 **Equation 2-7**

1206 Where,

1207 M_i = Mass of stock liquid or distillate (lb)

1208 ρ_i = Density of stock liquid or distillate (lb/gal)

1209 **7.48** = Conversion factor converting cubic feet to gallons (gal/ft³)

1210

1211 **Step 3 – Determine the number of moles of each component in the mixture.** The moles of
1212 each component are calculated by taking the mass calculated in the previous step and dividing
1213 by the respective liquid molecular weight as follows.

1214
$$n_i = \frac{M_i}{M_L}$$

1215 **Equation 2-8**

1216 Where,

1217 n_i = Number of moles of stock liquid or distillate remaining in the tank (mol)

1218 M_L = Liquid molecular weight of the stock liquid or distillate (lb/mol)

1219

1220 **Step 4 – Determine the mole (volume) fractions of each component in the mixture.** This is
1221 calculated by taking the moles of each component and dividing by the total moles in the liquid
1222 mixture as shown.

1223
$$x_i = \frac{n_i}{n_{tot}}$$

1224 **Equation 2-9**

1225 Where,

1226 x_i = Mol fraction of stock liquid or distillate

1227 n_{tot} = Total amount of all constituents in the mixture (mol)

1228

1229 **Step 5 – Calculate the partial pressure of each component in the mixture.** The partial
 1230 pressure of each component is the product of the component mol fraction and the respective
 1231 true vapor pressure.

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

Equation 2-10

1232
 1233

1234 Where,

1235 **P_i** = Partial pressure of stock liquid or distillate (psia)

1236

1237 **Step 6 – Calculate the vapor space purge emissions.** Substitute the value of P_i from the
 1238 previous step for P_{VA} into Equation 2-2 to get L_P for each component and sum both for the total
 1239 vapor space purge emissions of the mixture for this step of the storage tank cleaning.

$$\sum_i^n (L_P)_i$$

1240

Equation 2-11

1241

1242

1243 2.4.2 Continued Forced Ventilation Emissions

1244 After the storage tank has been drained and the vapor space purged, there may still be some
 1245 volatile materials remaining. These materials will continue to generate vapors, and generally
 1246 the eductors, fans, or blowers used to purge the vapor space will be activated again. This
 1247 marks the beginning of the continued forced ventilation process. The vapor concentration may
 1248 be monitored during this time for safety purposes and are often reported as a percent of the
 1249 lower explosive limit, or %LEL. Emissions generated during this portion of the bulk storage
 1250 tank cleaning process depend upon the ventilation rate and the length of time of the continued
 1251 forced ventilation operation. An estimate of the generated emissions may be calculated as
 1252 follows.

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

Equation 2-12

1253

1254

1255

1256 Where,

1257 **Q_v** = Average ventilation rate (ft³/min)

1258 **n_{CV}** = Duration of the continued forced ventilation (days)

1259 **t_v** = Daily period of forced ventilation (hr/day)

1260 **C_v** = Average vapor concentration by volume. May either be taken from an organic
 1261 vapor analyzer or toxic vapor analyzer that provides a direct reading of the
 1262 volume concentration. If %LEL readings are available, this term may be
 1263 calculated as given in Equation 2-13.

- 1264 **P_a** = Atmospheric pressure at the tank location (psia)
 1265 **M_{CG}** = Calibration gas molecular weight (lb/lb-mole)
 1266 **R** = Ideal gas constant, **10.731** (psia • ft³ / lb-mol • °R)
 1267

$$1268 \quad C_V = \left(\frac{\%LEL_{avg} \times \%LEL_{CG}}{100} \right) \times RF$$

1269 **Equation 2-13**

1270 Where,

- 1271 **%LEL** = Average %LEL readings by measurement device
 1272 **%LEL_{CG}** = %LEL of the gas used to calibrate the LEL monitor
 1273 **100** = Factor converting percent to a fraction (%)
 1274 **RF** = Response factor. Use 1.0 if unknown.
 1275

1276 Note that the emissions generated from continued forced ventilation should be compared to an
 1277 upper limit of emissions to avoid unnecessarily conservative estimates. The upper limit of
 1278 emissions generated from continued forced ventilation is dependent upon whether the tank
 1279 contains free standing stock liquid or volatile sludge. If the tank does contain free standing
 1280 stock liquid, the upper limit may be expressed as follows.

$$1281 \quad L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

1282 **Equation 2-14**

1283 Where,

- 1284 **5.9** = Equation constant (gal/ft³)
 1285 **h_{le}** = Effective height of the stock liquid. This is an estimate of the depth of the
 1286 remaining liquid in the tank and sump if spread across the entire tank bottom.
 1287 **W_l** = Density of the stock liquid (lb/gal)
 1288

1289 After the free-standing stock liquid has been drained, any remaining sludge will consist of non-
 1290 volatile material. The upper limit of emissions in this instance is given as follows.

$$1291 \quad L_{CV} \leq 0.49 \times F_e \times D^2 \times d_s \times W_l$$

1292 **Equation 2-15**

1293 Where,

- 1294 **0.49** = Equation constant (gal/in•ft²)
 1295 **F_e** = Fraction of the sludge with the potential to evaporate. **Use 0.20 if unknown.**
 1296 **d_s** = Average sludge depth (in)
 1297

1298 **2.5 Information Resources**

1299 For a complete list of storage tanks located on base, as well as information concerning the
 1300 content of each tank, contact the Base Supply Fuels Management or Civil Engineering Liquid

1301 Fuels shop. These offices should also be able to provide necessary tank characteristic data,
1302 such as tank type, dimensions, volume, and tank condition. For information pertaining to fuel
1303 service stations, it may be necessary to also contact the service station supervisor.

1304

1305 **2.6 Example Problems**

1306 **2.6.1 Problem #1 - Tank Cleaning Without Distillate Flushing**

1307 A USAF Base is looking at calculating emissions from the cleaning of one of their gasoline
1308 (RVP 7.8, density 6.15 lb/gal) storage tanks located on base. The tank is a fixed cone roof, flat
1309 bottom tank with a diameter of 60 feet, and a height of 20 feet. After the tank is drained,
1310 cleaning commenced with a vapor space purge where the emissions were routed to a control
1311 device with a 94% control efficiency. At the start of forced ventilation, one inch of gasoline is
1312 conservatively assumed to remain at the bottom of the tank. Another 3 inches is assumed to
1313 remain in the bottom of a 24-inch sump. Additionally, half an inch of wet sludge remains. The
1314 forced ventilation operated at 1,800 cubic feet per minute (cfm) with the emissions still routed
1315 to the control device. An average vapor concentration over this period was measured at 28,000
1316 ppmv and the calibration gas molecular weight is 16.04 lb/lb-mol. After 24 hours, the control
1317 device was disconnected, and the tank was ventilated to the atmosphere while the forced
1318 ventilation continued. During this time, the sludge, estimated to now be a quarter of an inch,
1319 was removed and the tank was rinsed. After 8 hours, the tank was deemed to be clean and
1320 vapor free. The average vapor concentration for this day was measured at 1,500 ppmv.
1321 Assuming an average temperature of 70°F and pressure of 14.7 psia for both days, calculate the
1322 total emissions generated from this tank cleaning event.

1323

1324 **Step 1 – Calculate the roof outage.** Prior to calculation of the emissions due to the vapor
1325 space purge, the total vapor space volume must be determined. The initial step in calculating
1326 this value is the determination of the roof outage. The problem stated that the tank has a fixed
1327 cone roof. A slope was not provided; therefore, a typical value of **0.0625ft/ft** may be used.
1328 Using this value and the stated tank diameter of **60ft**, the roof outage is calculated using
1329 Equation 2-4.

$$1330 \quad H_{RO} = \frac{1}{6} \times S_R \times D$$

$$1331 \quad H_{RO} = \frac{1}{6} \times 0.0625 \frac{ft}{ft} \times 60ft$$

$$1332 \quad H_{RO} = \frac{1}{6} \times 3.75ft = \mathbf{0.625ft}$$

1333

1334 **Step 2 – Determine the vapor space height.** The problem stated that after being drained, an
1335 inch of gasoline remains. With a shell height of **20ft**, the vapor space height is estimated as
1336 follows:

1337
$$H = 20ft - \frac{1in}{12in/ft}$$

1338
$$H = 20ft - 0.0833 ft = \mathbf{19.917 ft}$$

1339

1340 **Step 3 – Calculate the vapor space volume.** With the roof outage calculated in Step 1 and
 1341 vapor space height calculated in Step 2, the vapor space volume may be calculated using
 1342 Equation 2-3 as follows:

1343
$$V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

1344
$$V_V = \frac{\pi \times 60^2 ft^2}{4} \times (19.917 ft + 0.625 ft)$$

1345
$$V_V = \frac{\pi \times 60^2 ft^2}{4} \times (20.542 ft) = \mathbf{58,080.19 ft^3}$$

1346

1347 **Step 4 – Identify and record the vapor molecular weight and true vapor pressure.** Vapor
 1348 space purge emissions are dependent upon the characteristics of the fuel. Given that the
 1349 problem stated that the average temperature was 70°F, the vapor molecular weight and true
 1350 vapor pressure, according to Table 2-1, for gasoline with a Reid vapor pressure (RVP) of 7.8
 1351 are **68 lb/lb-mol** and **4.79 psia** respectively.

1352

1353 **Step 5 - Calculate the vapor space purge emissions.** The emissions generated during the
 1354 vapor space purge are those that occur initially when the blowers were activated on the tank.
 1355 The total emitted product is determined using Equation 2-2 and the calculated and recorded
 1356 parameters as shown:

1357
$$L_P = \left(\frac{P_{VA} \times V_V}{R \times T_V} \right) \times M_V \times S \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

1358
$$L_P = \left(\frac{4.79 \times 58,080.19}{10.731 \times 529.67} \right) \frac{psia \ ft^3 \ lb-mol \ ^\circ R}{psia \ ft^3 \ ^\circ R} \times 68 \frac{lb}{lb-mol} \times 0.5 \times [1 - (0.94)]$$

1359
$$L_P = \left(\frac{4.79 \times 58,080.19}{10.731 \times 529.67} \right) \frac{psia \ ft^3 \ lb-mol \ ^\circ R}{psia \ ft^3 \ ^\circ R} \times 68 \frac{lb}{lb-mol} \times 0.5 \times [0.06]$$

1360
$$L_P = (48.95) \frac{lb}{lb-mol} \times 68 \frac{lb}{lb-mol} \times 0.5 \times [0.06]$$

1361
$$L_P = 3,328.33 lb \times 0.5 \times 0.06 = \mathbf{99.85 lb}$$

1362

1363 **Step 6 – Calculate the effective height of the remaining stock liquid and sludge.** At the
 1364 start of the continued forced ventilation, an estimated height of one inch of gasoline is
 1365 remaining. Additionally, it is stated that another 3 inches of fuel are in a 24-inch diameter

1366 sump. The effective height is estimated by first estimating the equivalent depth of the gasoline
 1367 in the sump and then adding this to the gasoline remaining at the bottom of the tank as follows:

1368
$$h_s = depth \times \frac{D_S^2}{D_T^2}$$

1369
$$h_s = \frac{3 \text{ in}}{12 \text{ in/ft}} \times \frac{(24 \text{ in}/12 \text{ in/ft})^2}{(60 \text{ ft})^2} = 0.00028 \text{ ft}$$

1370
$$h_{le} = 0.00028 \text{ ft} + \frac{1 \text{ in}}{12 \text{ in/ft}} = \mathbf{0.0836 \text{ ft}}$$

1371
 1372 **Step 7 – Calculate the upper limit of the emissions from the continued ventilation for the**
 1373 **first 24 hours.** This is done using Equation 2-14 as follows:

1374
$$L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

1375
$$L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times (60 \text{ ft})^2 \times 0.0836 \text{ ft} \times 6.15 \frac{\text{lb}}{\text{gal}}$$

1376
$$L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times 300.96 \text{ ft}^3 \times 6.15 \frac{\text{lb}}{\text{gal}}$$

1377
$$L_{CV} \leq 1775.664 \text{ gal} \times 6.15 \frac{\text{lb}}{\text{gal}} = \mathbf{10,920.33 \text{ lb}}$$

1378
 1379 **Step 8 – Calculate the emissions from the continued ventilation for the first 24 hours and**
 1380 **compare to the upper limit calculated above.** Note that, during this time, the ventilated air is
 1381 still flowing through a control device. Using Equation 2-12 and the data provided in the
 1382 problem statement, the emissions generated from the continued ventilation during the first day
 1383 are calculated as follows:

1384
$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V} \right) \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

1385
$$L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 24 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times$$

 1386
$$\left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times (70 + 459.67) \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times \left[1 - \left(\frac{94\%}{100\%} \right) \right]$$

1387
 1388
$$L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 24 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times$$

 1389
$$\left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times 529.67 \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times [1 - (.94)]$$

1390
$$L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 24 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) \times [0.06]$$

1391
$$L_{CV} = 72,576 \text{ ft}^3 \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) \times [0.06] = \mathbf{180.71 \text{ lb}} \leq 10,920.33 \text{ lb} \checkmark$$

1392

1393 **Step 9 – Calculate the upper limit of the emissions from the continued ventilation for the**
 1394 **remaining time.** This is done using Equation 2-15 as follows:

1395
$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_s \times W_l$$

1396
$$L_{CV} \leq 0.49 \frac{\text{gal}}{\text{in} \cdot \text{ft}^2} \times 0.20 \times (60 \text{ ft})^2 \times 0.25 \text{ in} \times 6.15 \frac{\text{lb}}{\text{gal}}$$

1397
$$L_{CV} \leq 441 \text{ gal} \times 0.20 \times 6.15 \frac{\text{lb}}{\text{gal}} = \mathbf{542.43 \text{ lb}}$$

1398

1399 **Step 10 – Calculate the emissions from the continued ventilation for the remaining time**
 1400 **and compare to the upper limit calculated above.** Note that, during this time, the ventilated
 1401 air is no longer flowing through a control device. Using Equation 2-12 and the data provided
 1402 in the problem statement, the emissions generated from the continued ventilation during the
 1403 remaining time are calculated as follows:

1404
$$L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V} \right) \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

1405
$$L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{1,500}{10^6} \times \left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times 529.67 \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times$$

 1406
$$\left[1 - \right.$$

 1407
$$\left. \left(\frac{0\%}{100\%} \right) \right]$$

 1408

1409
$$L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{1,500}{10^6} \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right)$$

1410
$$L_{CV} = 1296 \text{ ft}^3 \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) = \mathbf{53.78 \text{ lb}} \leq 542.43 \text{ lb} \checkmark$$

1411

1412 **Step 11 – Calculate the total emissions from this bulk storage tank cleaning event.** Sum
 1413 the emissions from the vapor space purge and continued ventilation using Equation 2-1 as
 1414 follows:

1415
$$L_{FV} = L_P + L_{CV}$$

1416
$$L_{FV} = 99.85 \text{ lb} + (180.71 + 53.78) \text{ lb}$$

$$L_{FV} = 334.34 \text{ lb}$$

1417
1418

1419 2.6.2 Problem #2 – Tank Cleaning with Distillate Flushing

1420 Assume a storage tank is cleaned using a similar process and the same information as given in
1421 Problem #1. However, in this case, assume that after the initial purge, the tank is flushed with
1422 diesel fuel (7.14 lb/gal) that equates to about four inches in total depth. Forced ventilation
1423 resumed and continued overnight and into the second day (for a total of 18 hours) while still
1424 connected to the control device. At the start of the second day, the gasoline/diesel mixture is
1425 vacuumed out, leaving a half inch of wet sludge. Forced ventilation resumes after
1426 disconnecting the control device and continues for 8 hours while the sludge is removed. At the
1427 end of the second day, the forced ventilation was turned off and the average vapor
1428 concentration was calculated as 4,400 ppmv. Approximately 1/8 inch of wet sludge was
1429 estimated to remain. Finally, at the start of the third day, forced ventilation resumed while the
1430 remaining sludge was removed. Forced ventilation was terminated after 8 hours and the
1431 average vapor concentration was calculated as 1,000 ppmv. The tank was rinsed and
1432 completely clean by the end of the third day. The temperature and pressure recorded for the
1433 third day remained steady at 70°F and 14.7 psia respectively.
1434

1435 **Step 1 – Calculate the roof outage, vapor space height, vapor space volume and calculate**
1436 **the vapor space purge emissions for the first day.** Since the tank dimensions and the
1437 temperature and pressure measurements in this problem are the same as given in Problem #1,
1438 this initial step is the same as Steps 1 -5 from Problem #1. The total calculated emissions from
1439 the first day's vapor space purge were calculated as **99.85 lb**.

1440
1441 **Step 2 – Calculate the upper limit of the emissions from the continued ventilation for the**
1442 **first 24 hours.** In this problem, distillate was added to flush the tank. The total diesel added
1443 was determined to be equivalent to 4 inches in depth. Using this value, the given density of the
1444 diesel (**7.14 lb/gal**) the density of the gasoline as given in Problem #1 (**6.15 lb/gal**), and the
1445 effective height of the gasoline as calculated in Step 6 of Problem # 1 (**0.0836 ft**) the upper
1446 limit is calculated using Equation 2-14 as follows:

$$1447 \quad L_{CV} \leq 5.9 \times D^2 \times h_{le} \times W_l$$

$$1448 \quad L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times (60 \text{ ft})^2 \times \left[\left(0.0836 \text{ ft} \times 6.15 \frac{\text{lb}}{\text{gal}} \right) + \left(\frac{4 \text{ in}}{12 \text{ in/ft}} \times 7.14 \frac{\text{lb}}{\text{gal}} \right) \right]$$

$$1449 \quad L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times (60 \text{ ft})^2 \times \left[\left(2.894 \frac{\text{ft lb}}{\text{gal}} \right) \right]$$

$$1450 \quad L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times 3600 \text{ ft}^2 \times \left(2.894 \frac{\text{ft lb}}{\text{gal}} \right)$$

$$1451 \quad L_{CV} \leq 5.9 \frac{\text{gal}}{\text{ft}^3} \times 10,418.4 \frac{\text{ft}^3 \text{ lb}}{\text{gal}} = \mathbf{61,468.56 \text{ lb}}$$

1452

1453 **Step 3 – Calculate the emissions from the continued ventilation for the first 24 hours and**
 1454 **compare to the upper limit calculated above.** Note that, during this time, the ventilated air is
 1455 still flowing through a control device. Using Equation 2-12 and the data provided in the
 1456 problem statement, the emissions generated from the continued ventilation during the first day
 1457 are calculated as follows:

$$1458 \quad L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V} \right) \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

$$1459 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 18 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times$$

$$1460 \quad \left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times (70 + 459.67) \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times \left[1 - \left(\frac{94\%}{100\%} \right) \right]$$

1461

$$1462 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 18 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times$$

$$1463 \quad \left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times 529.67 \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times [1 - (.94)]$$

$$1464 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 18 \frac{\text{hr}}{\text{day}} \times \frac{28,000}{10^6} \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) \times [0.06]$$

$$1465 \quad L_{CV} = 54,432 \text{ ft}^3 \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) \times [0.06] = \mathbf{135.54 \text{ lb}} \leq 61,468.56 \text{ lb} \checkmark$$

1466

1467 **Step 4 – Calculate the upper limit of the emissions from the continued ventilation for the**
 1468 **second day.** Note that, in this example problem there is both gasoline and diesel remaining in
 1469 the tank. However, since the density of the diesel fuel is greater than that of gasoline (7.14 vs
 1470 6.15 lb/gal) and the remaining liquid is comprised of more diesel than gasoline, it would be
 1471 acceptable to calculate a conservative upper limit using the density of the diesel fuel. The
 1472 conservative upper limit is therefore calculated using Equation 2-15 as follows:

$$1473 \quad L_{CV} \leq 0.49 \times F_e \times D^2 \times d_s \times W_l$$

$$1474 \quad L_{CV} \leq 0.49 \frac{\text{gal}}{\text{in} \cdot \text{ft}^2} \times 0.20 \times (60 \text{ ft})^2 \times 0.5 \text{ in} \times 7.14 \frac{\text{lb}}{\text{gal}}$$

$$1475 \quad L_{CV} \leq 882 \text{ gal} \times 0.20 \times 7.14 \frac{\text{lb}}{\text{gal}} = \mathbf{1,259.5 \text{ lb}}$$

1476

1477 **Step 5 – Calculate the emissions from the continued ventilation for the second day and**
 1478 **compare to the upper limit calculated above.** Note that, during this time, the ventilated air is

1479 no longer flowing through a control device. Using Equation 2-12 and the data provided in the
 1480 problem statement, the emissions generated from the continued ventilation during the
 1481 remaining time are calculated as follows:

$$1482 \quad L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V} \right) \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

$$1483 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{4,400}{10^6} \times \left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times 529.67 \text{ R} \cdot \text{lb} \cdot \text{mol}} \right) \times$$

$$1484 \quad \left[1 - \right.$$

$$1485 \quad \left. \left(\frac{0\%}{100\%} \right) \right]$$

1486

$$1487 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{4,400}{10^6} \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right)$$

$$1488 \quad L_{CV} = 3,801.6 \text{ ft}^3 \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) = \mathbf{157.77 \text{ lb}} \leq 1,259.5 \text{ lb} \checkmark$$

1489

1490 **Step 6 – Calculate the volume of each component in the mixture.** Though most of the
 1491 diesel and gas mixture was vacuumed out the second day, a conservative estimate using their
 1492 respective depths (0.0836 ft for gasoline as calculated in Step 6 of Problem#1) and the tank
 1493 dimensions may be used to estimate their respective volumes using Equation 2-6.

$$1494 \quad V_i = h_i \times \frac{\pi \times D^2}{4}$$

$$1495 \quad V_{\text{gasoline}} = 0.0836 \text{ ft} \times \frac{\pi \times (60 \text{ ft})^2}{4} = \mathbf{236.37 \text{ ft}^3}$$

$$1496 \quad V_{\text{diesel}} = \frac{4 \text{ in}}{12 \text{ in/ft}} \times \frac{\pi \times (60 \text{ ft})^2}{4} = \mathbf{942.48 \text{ ft}^3}$$

1497

1498 **Step 7 – Calculate the mass of each component in the mixture.** Using the volume
 1499 calculated above, their respective densities, and Equation 2-7, the mass of each is estimated as
 1500 follows:

$$1501 \quad M_i = V_i \times \rho_i \times 7.48$$

$$1502 \quad M_{\text{gasoline}} = 236.37 \text{ ft}^3 \times 6.15 \frac{\text{lb}}{\text{gal}} \times 7.48 \frac{\text{gal}}{\text{ft}^3} = \mathbf{10,873.49 \text{ lb}}$$

$$1503 \quad M_{\text{diesel}} = 942.48 \text{ ft}^3 \times 7.14 \frac{\text{lb}}{\text{gal}} \times 7.48 \frac{\text{gal}}{\text{ft}^3} = \mathbf{50,335.22 \text{ lb}}$$

1504

1505 **Step 8 – Determine the number of moles of each component in the mixture.** Using
1506 Equation 2-8 and the liquid molecular weights of each component, as given in Table 2-1 (**92**
1507 **lb/lb-mol** for gasoline and **188 lb/lb-mol** for diesel), the number of moles of each component
1508 is calculated as follows:

$$1509 \quad n_i = \frac{M_i}{M_L}$$

$$1510 \quad n_{gasoline} = \frac{10,873.49 \text{ lb}}{92 \text{ lb/lb-mol}} = \mathbf{118.19 \text{ moles}}$$

$$1511 \quad n_{diesel} = \frac{50,335.22 \text{ lb}}{188 \text{ lb/lb-mol}} = \mathbf{267.74 \text{ moles}}$$

1512

1513 **Step 9 – Determine the mole (volume) fractions of each component in the mixture.** Using
1514 Equation 2-9, the mole fractions of each component are determined as follows:

$$1515 \quad x_i = \frac{n_i}{n_{tot}}$$

$$1516 \quad x_{gasoline} = \frac{118.19 \text{ mol}}{(118.19+267.74) \text{ moles}} = \mathbf{0.306}$$

$$1517 \quad x_{diesel} = \frac{267.74 \text{ mol}}{(118.19+267.74) \text{ moles}} = \mathbf{0.694}$$

1518

1519 **Step 10 – Calculate the partial pressure of each component in the mixture.** First, the true
1520 vapor pressure of each component at the specified temperature (70°F) is recorded from Table
1521 2-1. For gasoline (RVP 7.8) this is **4.79 psia** and for diesel it is **0.009 psia**. Using Equation
1522 2-10, the partial pressures from each component are calculated as follows:

$$1523 \quad P_i = x_i \times P_{VA}$$

$$1524 \quad P_{gasoline} = 0.306 \times 4.79 \text{ psia} = \mathbf{1.466 \text{ psia}}$$

$$1525 \quad P_{diesel} = 0.694 \times 0.009 \text{ psia} = \mathbf{0.00625 \text{ psia}}$$

1526

1527 **Step 11 – Calculate the vapor space volume.** At this point in the cleaning process, the
1528 mixture has been removed and only the sludge remains. Ignoring the depth of the sludge, the
1529 vapor space volume may be calculated using Equation 2-3 as follows:

$$1530 \quad V_V = \frac{\pi \times D^2}{4} \times (H + H_{RO})$$

$$1531 \quad V_V = \frac{\pi \times 60^2 \text{ ft}^2}{4} \times (20 \text{ ft} + 0.625 \text{ ft})$$

1532
$$V_V = \frac{\pi \times 60^2 \text{ ft}^2}{4} \times (20.625 \text{ ft}) = \mathbf{58,315.81 \text{ ft}^3}$$

1533

1534 **Step 12 – Calculate the vapor space purge emissions from each component from the third**
 1535 **day.** Since the forced ventilation was shut off at the end of the second day, vapors from both
 1536 the gasoline and diesel accumulated within the vapor space. Once the fans are restarted, the
 1537 initial purge results in emissions from each component. Those emissions are estimated using
 1538 Equation 2-2 as follows:

1539
$$L_P = \left(\frac{P_{VA} \times V_V}{R \times T_V} \right) \times M_V \times S \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

1540
$$L_{P \text{ Gasoline}} = \left(\frac{1.466 \times 58,315.81}{10.731 \times 529.67} \right) \frac{\text{psia ft}^3 \text{ lb-mol}^\circ \text{R}}{\text{psia ft}^3 \circ \text{R}} \times 68 \frac{\text{lb}}{\text{lb-mol}} \times 0.5 \times [1 - (0)]$$

1541
$$L_{P \text{ Gasoline}} = \left(\frac{1.466 \times 58,315.81}{10.731 \times 529.67} \right) \frac{\text{psia ft}^3 \text{ lb-mol}^\circ \text{R}}{\text{psia ft}^3 \circ \text{R}} \times 68 \frac{\text{lb}}{\text{lb-mol}} \times 0.5$$

1542
$$L_{P \text{ Gasoline}} = (15.04) \text{ lb-mol} \times 68 \frac{\text{lb}}{\text{lb-mol}} \times 0.5 = \mathbf{511.36 \text{ lb}}$$

1543
$$L_{P \text{ Diesel}} = \left(\frac{0.00625 \times 58,315.81}{10.731 \times 529.67} \right) \frac{\text{psia ft}^3 \text{ lb-mol}^\circ \text{R}}{\text{psia ft}^3 \circ \text{R}} \times 130 \frac{\text{lb}}{\text{lb-mol}} \times 0.5 \times [1 - (0)]$$

1544
$$L_{P \text{ Diesel}} = \left(\frac{0.00625 \times 58,315.81}{10.731 \times 529.67} \right) \frac{\text{psia ft}^3 \text{ lb-mol}^\circ \text{R}}{\text{psia ft}^3 \circ \text{R}} \times 130 \frac{\text{lb}}{\text{lb-mol}} \times 0.5$$

1545
$$L_{P \text{ Diesel}} = (0.064) \text{ lb-mol} \times 130 \frac{\text{lb}}{\text{lb-mol}} \times 0.5 = \mathbf{4.17 \text{ lb}}$$

1546

1547 **Step 13 – Calculate the vapor space purge emissions.** The total vapor space emissions
 1548 generated on the third day are the sum from each component and is calculated as follows:

1549
$$\sum_i^n (L_P)_i = (511.36 + 4.17) \text{ lb} = \mathbf{515.53 \text{ lb}}$$

1550

1551 **Step 14 – Calculate the upper limit of the emissions from the continued ventilation for the**
 1552 **remaining time.** This is done using Equation 2-15 as follows:

1553
$$L_{CV} \leq 0.49 \times F_e \times D^2 \times d_S \times W_l$$

1554
$$L_{CV} \leq 0.49 \frac{\text{gal}}{\text{in} \cdot \text{ft}^2} \times 0.20 \times (60 \text{ ft})^2 \times 0.125 \text{ in} \times 7.14 \frac{\text{lb}}{\text{gal}}$$

1555
$$L_{CV} \leq 220.5 \text{ gal} \times 0.20 \times 7.14 \frac{\text{lb}}{\text{gal}} = \mathbf{314.87 \text{ lb}}$$

1556

1557 **Step 15 – Calculate the emissions from the continued ventilation for the remaining time**
 1558 **and compare to the upper limit calculated above.** Note that, during this time, the ventilated
 1559 air is no longer flowing through a control device. Using Equation 2-12 and the data provided
 1560 in the problem statement, the emissions generated from the continued ventilation during the
 1561 remaining time are calculated as follows:

$$1562 \quad L_{CV} = 60 \times Q_V \times n_{CV} \times t_V \times C_V \times \left(\frac{P_a \times M_{CG}}{R \times T_V} \right) \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

$$1563 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{1,000}{10^6} \times \left(\frac{14.7 \text{ psia} \times 16.04 \text{ lb} \cdot \text{lb} \cdot \text{mol}^{-1} \cdot \text{R}}{10.731 \text{ psia} \cdot \text{ft}^3 \times 529.67 \text{ R} \cdot \text{lb} \cdot \text{mol}^{-1}} \right) \times$$

$$1564 \quad \left[1 - \right.$$

$$1565 \quad \left. \left(\frac{0\%}{100\%} \right) \right]$$

$$1566$$

$$1567 \quad L_{CV} = 60 \frac{\text{min}}{\text{hr}} \times 1800 \frac{\text{ft}^3}{\text{min}} \times 1 \text{ day} \times 8 \frac{\text{hr}}{\text{day}} \times \frac{1,000}{10^6} \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right)$$

$$1568 \quad L_{CV} = 864 \text{ ft}^3 \times \left(\frac{0.0415 \text{ lb}}{\text{ft}^3} \right) = 35.86 \text{ lb} \leq 314.87 \text{ lb} \checkmark$$

1569
 1570 **Step 16 – Calculate the total emissions from this bulk storage tank cleaning event.** Sum
 1571 the emissions from the vapor space purges and continued ventilation for all three days using
 1572 Equation 2-1 as follows:

$$1573 \quad L_{FV} = L_P + L_{CV}$$

$$1574 \quad L_{FV} = (99.85 + 515.53) \text{ lb} + (135.54 + 157.77 + 35.86) \text{ lb}$$

$$1575 \quad \boxed{L_{FV} = 944.55 \text{ lb}}$$

1576

1577 **2.7 References**

1578 40 CFR 63 Subpart OO, “Title 40-Protection of the Environment, Chapter I-Environmental
1579 Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for
1580 Hazardous Air Pollutants for Source Categories, Subpart OO-National Emission Standards for
1581 Tanks – Level 1,” U.S. Environmental Protection Agency

1582 40 CFR 63 Subpart WW, “Title 40-Protection of the Environment, Chapter I-Environmental
1583 Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for
1584 Hazardous Air Pollutants for Source Categories, Subpart WW-National Emission Standards for
1585 Storage Vessels (Tanks) – Control Level 2,” U.S. Environmental Protection Agency

1586 40 CFR 63 Subpart EEEE, “Title 40-Protection of the Environment, Chapter I-Environmental
1587 Protection Agency, Subchapter C-Air Programs, Part 63-National Emission Standards for
1588 Hazardous Air Pollutants for Source Categories, Subpart EEEE-National Emission Standards
1589 for Hazardous Air Pollutants” Organic Liquids Distribution (Non-gasoline),” U.S.
1590 Environmental Protection Agency

1591 40 CFR 63 Subpart CCCCCC, “Title 40-Protection of the Environment, Chapter I-
1592 Environmental Protection Agency, Subchapter C-Air Programs, Part 63-National Emission
1593 Standards for Hazardous Air Pollutants for Source Categories, Subpart CCCCCC-National
1594 Emission Standards for Hazardous Air Pollutants for Source Category: Gasoline Dispensing
1595 Facilities,” U.S. Environmental Protection Agency

1596 Mayfield 1996, “JP-8 Composition and Variability,” Armstrong Laboratory, Environics
1597 Directorate, Environmental Research Division, May 1996

1598 USEPA 2016, “TANKS Software Frequent Questions.” EPA,
1599 <https://www3.epa.gov/ttnchie1/faq/tanksfaq.html#13>. Accessed November 2014

1600 USEPA 2020, Section 7.1-“Organic Liquid Storage Tanks,” Compilation of Air Pollutant
1601 Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S.
1602 Environmental Protection Agency, June 2020

1603

1604
1605

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1606 3 BURN, OPEN (OB)

1607 ➤ *Fugitive Source*

1608

1609 3.1 Introduction

1610 Open burning is the burning of unwanted material in the open air where smoke and emissions
1611 are released into the atmosphere directly. Open burning is generally done outdoors where
1612 waste materials are burnt as a means of waste disposal, away from an incinerator or a furnace
1613 chamber. Open burning can be done in open drums or baskets, in fields and yards, and in large
1614 open dumps or pits. **Open burning operations result in the fugitive emissions of criteria
1615 pollutants and greenhouse gases.**

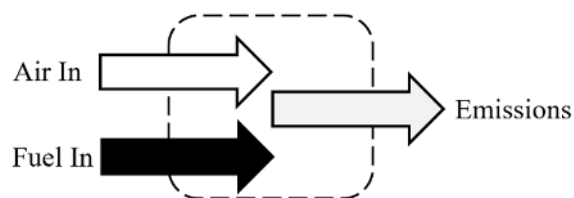
1616

1617 3.1.1 Open Burning

1618 Open burning is defined as the combustion of materials in unenclosed areas such as in open
1619 drums, baskets, fields, or in pits. Materials commonly disposed of in this manner include
1620 municipal waste, auto body components, landscape refuse, agricultural field refuse, wood
1621 refuse, bulky industrial refuse, and leaves. Federal regulations prohibit the open burning of
1622 hazardous waste, apart from explosive ordnance, whose emissions calculations are described in
1623 the *Air Emissions Guide for Air Force Stationary Sources*.

1624

1625 Emissions from the open burning of agricultural materials are dependent on the moisture
1626 content and compactness of the material as well as whether the refuse is burned in a headfire or
1627 backfire. Headfires are started at the upwind side of a field and allowed to progress in the
1628 direction of the wind whereas backfires start at the downwind edge and progress in a direction
1629 opposing the wind. How the refuse is arranged, such as in piles, rows, or spread out, can
1630 influence the emissions as well. A simple control volume for open burns is provided in Figure
1631 3-1.



1632

1633 **Figure 3-1. Simplified Open/Prescribed Burn Control Volume**

1634 3.2 NSPS Applicability

1635 There are several NSPS that have been set by the EPA and apply specifically to air curtain
1636 incinerators, also known as trench combustors, which may be used for open burning purposes.

1637 For any installation that uses air curtain incinerators, it is assumed that they combust 100
1638 percent wood or yard waste, which exempts these incinerators from several NSPS provisions.
1639 However, there are several opacity emissions limits, testing requirements, and reporting and
1640 record keeping provisions in which these air curtain incinerators are still required to abide.
1641 Both the size of the air curtain incinerator and the date it was constructed determines the
1642 standards that may apply. The following subparts to 40 CFR 60 have provisions specific to air
1643 curtain incinerators:

1644 • Subpart Cb – Emissions Guidelines and Compliance Times for Large Municipal Waste
1645 Combustors that are Constructed on or Before September 20, 1994

1646 • Subpart Eb – Standards of Performance for Large Municipal Waste Combustors for
1647 Which Construction is Commenced After September 20, 1994, or for Which
1648 Modification or Reconstruction is Commenced After June 19, 1996

1649 • Subpart AAAA – Standards of Performance for Small Municipal Waste Combustion
1650 Units for Which Construction is Commenced After August 30, 1999, or for Which
1651 Modification or Reconstruction is Commenced After June 6, 2001

1652 • Subpart BBBB – Emission Guidelines and Compliance Times for Small Municipal
1653 Waste Combustion Units Constructed on or Before August 30, 1999

1654 • Subpart CCCC – Standards of Performance for Commercial and Industrial Solid Waste
1655 Incineration Units

1656 • Subpart DDDD – Emissions Guidelines and Compliance Times for Commercial and
1657 Industrial Solid Waste Incineration Units

1658 • Subpart EEEE – Standards of Performance for Other Solid Waste Incineration Units for
1659 Which Construction is Commenced After December 9, 2004, or for Which
1660 Modification or Reconstruction is Commenced on or After June 16, 2006

1661 • Subpart FFFF – Emission Guidelines and Compliance Times for Other Solid Waste
1662 Incineration Units that Commenced Construction on or Before December 9, 2004
1663

1664 For more information regarding the standards applicable to air curtains, refer to the appropriate
1665 subpart in 40 CFR 60.
1666

1667 **3.3 Emissions Factors**

1668 Open burning emissions are affected by many variables, including wind, ambient temperature,
1669 composition, and moisture content of the debris burned, and compactness of the pile. In
1670 general, the relatively low temperatures associated with open burning increase emissions of
1671 particulate matter, carbon monoxide, and hydrocarbons and suppress emissions of nitrogen
1672 oxides. Emissions of sulfur oxides are a direct function of the sulfur content of the refuse.
1673

1674 EFs have been developed for open burns based on the amount and type of material burned.
 1675 Sulfur oxide emissions are a direct function of the amount of sulfur in the material burned but
 1676 are typically negligible.

1677
 1678 AP-42 also provides EFs for several types of agricultural materials in units of pounds per ton of
 1679 refuse burned. Table 3-1 and Table 3-2 provide criteria pollutant EFs for the open burning of
 1680 municipal refuse and agricultural materials, respectively. Table 3-2 also provides average fuel
 1681 loading factors for different types of agricultural materials. The fuel loading factor is an
 1682 average estimate of the amount of material burned per unit of land (e.g., acre). Refer to
 1683 Chapter 2.5 of AP-42 for species specific EFs.

1684
 1685 Air curtain incinerators may be used as an alternative to traditional open burning. The purpose
 1686 of the air curtain is to reduce particulate emissions while improving the combustion efficiency
 1687 by applying a curtain of air across the top of an open pit where materials are being burned. Air
 1688 curtain incinerators are likely only to be used for open burning of agricultural materials. For
 1689 additional information, refer to Section 2.1 of AP-42.

1690 **Table 3-1. Criteria Pollutant Emission Factors for Municipal Refuse**

Source	Emission Factors (lb/ton)						
	NO _x	CO	SO _x	Pb	VOC ^a	PM ₁₀ ^b	PM _{2.5} ^b
Municipal Refuse	6	85	1	---	18	15.7	14.7
Automobile Components	4	125	---	---	15	98.3	91.6

1691
 1692 SOURCE (unless otherwise stated): Section 2.5 – “Open Burning, “Compilation of Air Pollutant Emission Factors – Volume I:
 1693 Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.

- 1694 a. VOC emission factor provided is the non-methane TOC emission factor provided in source document.
 1695 b. Source document provides emission factors for PM. These values calculated using the PM10 and PM2.5 fraction
 1696 from Krause, Mike and Steve Smith, “Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5
 1697 Significance Thresholds,” South Coast Air Quality Management District, October 2006.

1698

1699 **Table 3-2. Criteria Pollutant Emission Factors for Open Burning of Agricultural Materials**

Agricultural Material ^a	Fuel Loading Factor (ton/acre)	Emission Factors (lb/ton)						
		NO _x	CO	SO _x	Pb	VOC ^b	PM ₁₀ ^c	PM _{2.5} ^c
Field Crops	2	---	117	---	---	18	20.66	19.70
Grasses	---	---	101	---	---	15	15.74	15.01
Leaf Burning	---	---	112	---	---	28	37.39	35.64
Orchard Crops	1.6	---	52	---	---	8	5.89	5.55
Vine Crops	2.5	---	51	---	---	5	4.92	4.69
Weeds	3.2	---	85	---	---	9	14.76	14.07
Forest Residues - Unspecified	70	4	140	---	---	19	16.34	14.52
Forest Residues - Hemlock, Douglas Fir, Cedar	---	4	90	---	---	4	3.84	3.42
Forest Residues - Ponderosa Pine	---	4	195	---	---	11	11.53	10.25
Air Curtain Incinerators								
Wood ^d	---	1	2.6	0.1	---	0.9	1.30	0.87

- 1700 SOURCE (unless otherwise stated): Section 2.5 – “Open Burning, “Compilation of Air Pollutant Emission Factors – Volume I:
 1701 Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January 1995.
 1702
 1703 a. Unless otherwise specified, the agricultural material is “unspecified”.
 1704 b. VOC emission factor provided is the non-methane TOC emission factor provided in source document.
 1705 c. Source document provides emission factors for PM. These values calculated using the PM₁₀ and PM_{2.5} fraction from
 1706 Krause, Mike and Steve Smith, “Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5 Significance
 1707 Thresholds,” South Coast Air Quality Management District, October 2006.
 1708 d. SOURCE: Clerico, Brian, and Errol Villegas. “Air Curtain Incinerator Emissions Factors Determination.” Memo to Arnaud
 1709 Marjolle, Director of Permit Services, San Joaquin Valley Air Pollution Control. 4 Apr. 2017.
 1710 “---” – No Data Available.

1711 **Table 3-3. GHG Emission Factors for Open Burning of Agricultural Materials**

Agricultural Material ^a	Emission Factors (lb/ton)			
	CO ₂	N ₂ O	CH ₄ ^b	CO ₂ e ^c
Field Crops	2,149	0.08	5.4	2,307
Grasses	2,149	0.08	4.5	2,285
Leaf Burning	2,149	0.08	12	2,472
Orchard Crops	2,149	0.08	2.5	2,235
Vine Crops	2,149	0.08	1.7	2,215
Weeds	2,149	0.08	3.0	2,247
Forest Residues - Unspecified	3,615	0.14	5.7	3,799
Forest Residues - Hemlock, Douglas Fir, Cedar	3,615	0.14	1.2	3,686
Forest Residues - Ponderosa Pine	3,615	0.14	3.3	3,739
Air Curtain Incinerators				
Wood	3,615	0.14	0.28	3,663

- 1712 SOURCE (unless otherwise stated): “Title 40-Protection of the Environment, Chapter I-Environmental Protection Agency,
 1713 Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart C-General Stationary Fuel Combustion
 1714 Sources, U.S. Environmental Protection Agency.
 1715
 1716 a. Unless otherwise stated, the refuse category is “unspecified”.
 1717 b. SOURCE (excluding air curtain incinerators): Section 2.5 – “Open Burning,” Compilation of Air Pollutant Emission
 1718 Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, January
 1719 1995.
 1720 c. CO₂e calculated by summing the product of the emission factors for CO₂, N₂O, and CH₄ and their respective Global
 1721 Warming Potentials (GWP). The GWP for CO₂, N₂O, and CH₄ are 1, 298, and 25, respectively.

1722 3.4 Emissions Calculation

1723 For open burning, the EFs provided above are sufficient for the general calculation of
 1724 emissions. However, for enhanced accuracy, refer to Section 2.5 of AP-42 for more
 1725 information regarding species or region-specific EFs.

1726
 1727 Calculation of emissions from open burns is accomplished by taking the product of the total
 1728 mass burned and the respective EF as follows:

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

Equation 3-1

1731 Where,

1732 **E(Pol)** = Annual emission of pollutant from open/prescribed burns (lb/yr)

1733 **Q** = Annual mass of material burned (ton/yr)

1734 **EF(Pol)** = Emission factor for pollutant (lb/ton)

1735
 1736 The total annual mass of material burned is an estimated value. Best judgment should be used
 1737 when making this determination. For convenience, average fuel loading factors are provided in
 1738 Table 3-2 and may be used to estimate the mass burned as follows:

$$Q = A \times LF$$

Equation 3-2

1741 Where,

1742 **A** = Area burned (acres/yr)

1743 **LF** = Fuel loading factor (ton/acre)

1745 3.5 Example Problems

1746 3.5.1 Problem #1 (Open Burn)

1747 Last year, a USAF Base cleared 6.5 acres of land. The agricultural material on this land was
 1748 primarily weeds, which were disposed of through open burning. Calculate the CO, VOC,
 1749 PM₁₀, PM_{2.5}, and CO_{2e} emissions from this operation.

1750
 1751 **Step 1 – Select and record the fuel loading factor.** Since the quantity of weeds was not
 1752 provided in the problem statement, this value must be calculated. The first step involves
 1753 recording the fuel loading factor which, according to Table 3-2 is **3.2 ton/acre** for weeds.

1754
 1755 **Step 2 – Calculate the mass burned.** Using the total land cleared, the fuel loading factor
 1756 recorded in Step 1 and Equation 3-2, the mass burned is calculated as follows:

$$Q = A \times LF$$

$$1758 \quad Q = 6.5 \frac{\text{acre}}{\text{yr}} \times 3.2 \frac{\text{ton}}{\text{acre}} = 20.8 \frac{\text{ton}}{\text{yr}}$$

1759

1760 **Step 3 – Record emission factors.** According to Table 3-1 and Table 3-2, the EFs for CO,
 1761 VOC, PM₁₀, PM_{2.5} and CO_{2e} are **85, 9, 14.76, 14.07, and 2247 lb/ton**, respectively.

1762

1763 **Step 4 – Calculate emissions.** Using the mass burned as calculated in Step 2, the EFs
 1764 recorded in Step 3, and Equation 3-1, the emissions of each pollutant are calculated as follows:

$$1765 \quad E(\text{Pol}) = Q \times EF(\text{Pol})$$

$$1766 \quad E(\text{CO}) = 20.8 \frac{\text{ton}}{\text{yr}} \times 85 \frac{\text{lb}}{\text{ton}}$$

$$1767 \quad \boxed{E(\text{CO}) = 1,768 \frac{\text{lb}}{\text{yr}}}$$

$$1768 \quad E(\text{VOC}) = 20.8 \frac{\text{ton}}{\text{yr}} \times 9 \frac{\text{lb}}{\text{ton}}$$

$$1769 \quad \boxed{E(\text{VOC}) = 187.2 \frac{\text{lb}}{\text{yr}}}$$

$$1770 \quad E(\text{PM}_{10}) = 20.8 \frac{\text{ton}}{\text{yr}} \times 14.76 \frac{\text{lb}}{\text{ton}}$$

$$1771 \quad \boxed{E(\text{PM}_{10}) = 307.0 \frac{\text{lb}}{\text{yr}}}$$

$$1772 \quad E(\text{PM}_{2.5}) = 20.8 \frac{\text{ton}}{\text{yr}} \times 14.07 \frac{\text{lb}}{\text{ton}}$$

$$1773 \quad \boxed{E(\text{PM}_{2.5}) = 292.7 \frac{\text{lb}}{\text{yr}}}$$

$$1774 \quad E(\text{GHG}) = 20.8 \frac{\text{ton}}{\text{yr}} \times 2247 \frac{\text{lb}}{\text{ton}}$$

$$1775 \quad \boxed{E(\text{GHG}) = 46,737.6 \frac{\text{lb}}{\text{yr}}}$$

1776

1777

1778

1779 **3.6 References**

- 1780 40 CFR 60 Subpart Cb, “Title 40-Protection of the Environment, Chapter I-Environmental
1781 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1782 Stationary Sources, Subpart Cb-Emissions Guidelines and Compliance Times for Large
1783 Municipal Waste Combustors that are Constructed on or Before September 20, 1995,” U.S.
1784 Environmental Protection Agency
- 1785 40 CFR 60 Subpart Eb, “Title 40-Protection of the Environment, Chapter I-Environmental
1786 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1787 Stationary Sources, Subpart Eb-Standards of Performance for Municipal Waste Combustors for
1788 which Construction is Commenced After June 19, 1996,” U.S. Environmental Protection
1789 Agency
- 1790 40 CFR 60 Subpart AAAA, “Title 40-Protection of the Environment, Chapter I-Environmental
1791 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1792 Stationary Sources, Subpart AAAA-Standards of Performance for Small Municipal Waste
1793 Combustion Units for which Construction is Commenced After August 30, 1999,” U.S.
1794 Environmental Protection Agency
- 1795 40 CFR 60 Subpart BBBB, “Title 40-Protection of the Environment, Chapter I-Environmental
1796 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1797 Stationary Sources, Subpart BBBB-Emissions Guidelines and Compliance Times for Small
1798 Municipal Waste Combustion Units Constructed on or Before August 30, 1999,” U.S.
1799 Environmental Protection Agency
- 1800 40 CFR 60 Subpart CCCC, “Title 40-Protection of the Environment, Chapter I-Environmental
1801 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1802 Stationary Sources, Subpart CCCC-Standards of Performance for Commercial and Industrial
1803 Solid Waste Incineration Units,” U.S. Environmental Protection Agency
- 1804 40 CFR 60 Subpart DDDD, “Title 40-Protection of the Environment, Chapter I-Environmental
1805 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1806 Stationary Sources, Subpart DDDD-Emissions Guidelines and Compliance Times for
1807 Commercial and Industrial Solid Waste Incineration Units,” U.S. Environmental Protection
1808 Agency
- 1809 40 CFR 60 Subpart EEEE, “Title 40-Protection of the Environment, Chapter I-Environmental
1810 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1811 Stationary Sources, Subpart EEEE-Standards of Performance for Other Solid Waste
1812 Incineration Units for which Construction is Commenced After December 9, 2004, or for

- 1813 which Modification or Reconstruction is Commenced on or After June 16, 2006,” U.S.
1814 Environmental Protection Agency
- 1815 40 CFR 60 Subpart FFFF, “Title 40-Protection of the Environment, Chapter I-Environmental
1816 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
1817 Stationary Sources, Subpart FFFF-Emissions Guidelines and Compliance Times for Other
1818 Solid Waste Incineration Units that Commenced Construction on or Before December 9,
1819 2004,” U.S. Environmental Protection Agency
- 1820 40 CFR 60 Subpart C, “Title 40-Protection of the Environment, Chapter I-Environmental
1821 Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas
1822 Reporting, Subpart C-General Stationary Fuel Combustion Sources,” U.S. Environmental
1823 Protection Agency
- 1824 40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
1825 Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart
1826 C-
- 1827 USEPA 1995, Section 2.5-“Open Burning,” Compilation of Air Pollutant Emission Factors –
1828 Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection
1829 Agency, January 1995
- 1830
1831
1832
1833
1834

1835 4 CONSTRUCTION (CNST)

1836 ➤ (Primarily) Fugitive Source – Construction Equipment and Activity

1837

1838 ***This category is not included in an AEI since, unlike the other sections of this document,**
1839 **it describes calculations of emissions for a proposed action, not actual emissions, which**
1840 **are conditionally mobile or stationary***

1841

1842 4.1 Introduction

1843 Emissions from construction activities may vary from day to day depending on the level of
1844 activity, the phase of the construction process, and meteorological conditions. **Emissions of**
1845 **concern from construction include criteria pollutants and greenhouse gases and may be**
1846 **either point or fugitive.** Much of the emissions from construction are the result of exhaust
1847 from motorized vehicles/equipment whose emissions calculations are described in the *Air*
1848 *Emissions Guide for Air Force Mobile Sources.*

1849

1850 The total emissions resulting from construction operations are the sum of the pollutant emitting
1851 activities that occur during each phase of construction. Emissions from construction operations
1852 include emissions of the equipment involved in the construction activity, vehicle emissions
1853 from the workers commuting to the construction site, and emissions from the activity itself.
1854 Calculating emissions from each phase involves acquiring some site data such as the area and
1855 volume of the construction activity, and the average commuting distance for the workers.
1856 Programs such as the Air Conformity Applicability Model (ACAM) or other approved models,
1857 may calculate emissions from each phase of the construction process using user input data or
1858 assumptions in lieu of site data. Many default values and algorithms for use in emissions
1859 calculations are taken from CALEEMOD and URBEMIS, emissions estimation computer
1860 programs developed for estimating emissions associated with land development projects.
1861 Vehicle exhaust emissions associated with land development projects may be estimated using
1862 their respective emission factors provided in OFFROAD. OFFROAD provides the most recent
1863 model outputs for many types of off-road equipment across several calendar years, model
1864 years, fuel, and horsepower ranges.

1865

1866 4.1.1 Construction Phases

1867 Generally, each construction project is unique; therefore, there is no one systematic approach to
1868 estimating emissions associated with construction. Because of this uniqueness, the preferred
1869 Air Force method is to separate construction into typical phases that result in quantifiable
1870 emissions. Construction operations may be classified as having six phases:

- 1871 1) Demolition
- 1872 2) Site Grading
- 1873 3) Trenching

- 1874 4) Excavation
 1875 5) Building Construction
 1876 6) Architectural Coating
 1877 7) Asphalt Paving

1878
 1879 Each construction phase results in a unique combination of construction emission classes, as
 1880 shown in Table 4-1. There are six construction emission classes that may contribute to the
 1881 emissions for any specific construction phase, which include:

- 1882 • Fugitive Dust,
 1883 • Construction Exhaust (Off-road equipment),
 1884 • Vehicle Exhaust (On-road vehicles),
 1885 • Worker Trips,
 1886 • Vendor Trips, and
 1887 • Off-Gassing.

1888

1889 **Table 4-1. Summary of Construction Phases and Their Emission Classes**

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

1890

1891 An "X" in a column indicates that emission class is considered in the overall emissions calculations for the phase. For
 1892 example, the "site grading" phase will consider Fugitive Dust, Construction Exhaust (Off-road equipment), Vehicle Exhaust
 1893 (On-road vehicles), and Worker Trips in calculating the overall emissions associated with site grading.

1894

1895 Demolition involves the tearing down of buildings or other obstacles and moving the
 1896 remaining debris off-site. Buildings may be demolished using loaders, bulldozers, demolition
 1897 excavators, or using carefully placed explosives that result in building implosions.

1898

1899 Site Grading is the process of altering the slope and elevation of land. This action is performed
 1900 to provide a stable base for the foundation of new construction and to improve drainage around
 1901 new or existing facilities.

1902

1903 Excavating involves the digging and removing of soil and rock. Excavated soil may be kept on-
1904 site for filling or backfilling open cavities, and for use in site grading. Any excess excavated
1905 material not used on-site is moved to an off-site location to be used elsewhere.

1906
1907 Trenching while generally the same process as excavating, occurs beneath the ground's
1908 surface, and they are narrow relative to their length. Typically trenching is used when laying
1909 pipes or cables for electricity or telecommunications.

1910
1911 The Building Construction phase introduces several different types of equipment depending on
1912 the scope of the project. These include cranes, forklifts, and loaders. The primary difference
1913 between the building construction phase and the other phases in construction from an air
1914 emissions standpoint, is that building construction does not typically produce fugitive dust
1915 emissions. However, emissions from vehicle exhaust increases during the building
1916 construction phase. The increase in vehicle exhaust is most often attributable to the influx of
1917 vendors making product deliveries to the construction site.

1918
1919 Architectural Coating involves the application of paint to the surface of standing structures.
1920 Painting applications result in the release of VOCs into the atmosphere due to the evaporation
1921 of solvents in the paint. Therefore, the amount of emissions is directly correlated to the
1922 composition and volume of the paint used.

1923
1924 Asphalt Paving is commonly used to surface roads and parking lots. Asphalt is composed of
1925 compacted aggregate, such as sand, gravel, and crushed stone, and an asphalt binder. The
1926 asphalt binder may be either asphalt cement or liquefied asphalt. Liquefied asphalt may be
1927 either asphalt cutbacks, which is produced by dissolving the binder with volatile petroleum
1928 distillates, or emulsified asphalts, which is an environmentally friendlier alternative to
1929 cutbacks. According to AP-42, "minor amounts of VOCs are emitted from emulsified asphalts
1930 and asphalt cement". This document provides the theoretical calculation of VOCs from asphalt
1931 paving and does not provide EFs for the calculation of actual emissions. This is due to the
1932 decline in cutback asphalt use in favor of emulsified asphalt. **The EF for VOCs from
1933 emulsified asphalt and asphalt cement are essentially assumed to be zero.**

1934

1935 **4.2 Emission Standards**

1936 To gradually decrease air emissions, the EPA has established air emission standards for
1937 nonroad engines whose full federal definition is provided in 40 CFR 1038.30. These standards,
1938 which apply to construction vehicles and equipment, establish multiple emission tiers with
1939 established compliance dates. The emission standards in which each engine must comply are
1940 based on that engine's size and year of manufacture. For more information regarding the
1941 nonroad engine standards and the year of implementation, refer to 40 CFR parts 89, 1068, and
1942 1039.

1943 4.3 Emissions Calculation

1944 The construction project emissions for a specific pollutant are estimated by summing the total
 1945 emissions (for the specific pollutant) for each of the six construction phases as shown below:

$$1946 \quad E(\text{Pol}) = \sum_{i=1}^n E(\text{Pol})_i$$

1947 **Equation 4-1**

1948 Where,

1949 **E(Pol)** = Emissions of individual pollutant for entire construction project (lb)

1950 **E(Pol)_i** = Emissions of individual pollutant for an individual construction phase (lb)

1951 **i** = Denotes the individual construction phase – i.e., Demolition, Site Grading,
 1952 Trenching/Excavation, Building Construction, Architectural Coatings, or
 1953 Asphalt Paving

1954

1955 Emissions of individual pollutants for each of the individual construction phases are estimated
 1956 by summing the emissions for all the phase components:

$$1957 \quad E(\text{Pol})_i = E(\text{Pol})_{\text{Fugitive Dust}} + E(\text{Pol})_{\text{Construction Exhaust}} + E(\text{Pol})_{\text{Vehicle Emissions}} \\ 1958 \quad + E(\text{Pol})_{\text{Worker Trips}} + E(\text{Pol})_{\text{Vendor Trips}} + E(\text{Pol})_{\text{Off-Gassing}}$$

1959 **Equation 4-2**

1960

1961 4.3.1 Fugitive Dust

1962 Significant atmospheric dust arises from the mechanical disturbance of granular material
 1963 exposed to the air during **demolition, site grading, trenching, and excavation** operations.
 1964 Dust generated from these sources is termed “fugitive” because it is not discharged to the
 1965 atmosphere in a confined flow stream. The dust-generation process is caused by two basic
 1966 physical phenomena:

- 1967 1. Pulverization and abrasion of surface materials by application of mechanical force
 1968 through implements (wheels, blades, etc.)
- 1969 2. Entrainment of dust particles by the action of turbulent air currents, such as wind
 1970 erosion of an exposed surface by wind speeds over 12 miles per hour (mph).

1971

1972 4.3.1.1 Demolition Fugitive Dust Emissions

1973 Fugitive dust emissions from the demolition phase of construction are a function of the volume
 1974 being demolished. The volume is calculated by taking the product of the building area and its
 1975 height. Fugitive dust emissions may be estimated by applying an EF to the area and height as
 1976 shown:

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

Equation 4-3

1977
1978
1979 Where,

1980 $E(PM_{10})$ = PM_{10} emissions (lb)

1981 0.00042 = Emission factor (lb/ft³)

1982 BA = Area of building to be demolished (ft²)

1983 BH = Height of building to be demolished (ft)

1984

1985 This equation is based on Table A9-9-H of the South Coast Air Quality Management District's
1986 (SCAQMD) California Environmental Quality Act Air Quality Handbook (SCAQMD 2007).

1987

1988 4.3.1.2 Site Grading, Excavation and Trenching Fugitive Dust Emissions

1989 The fugitive dust emissions may be estimated using the methodology developed for SCAQMD
1990 by the Midwest Research Institute. The following equation is used to estimate daily PM_{10}
1991 generated by site grading, excavation, and trenching using the default EF of 20 lb/acre-day
1992 (0.22 tons/acre-month at 22 days/month):

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

Equation 4-4

1993
1994
1995 Where,

1996 20 = Factor converting acre-day to lb (lb/acre-day)

1997 GA = Grading area (acre). **Note that, as a rule, the grading area should be about
1998 twice the size of the building being constructed.**

1999 WD = Work duration, estimated in workdays (days). **Note that this is workdays,
2000 not total duration days.**

2001

2002 4.3.2 Construction Exhaust (Off-Road Equipment) Emissions

2003 Emissions are generated by the operation of off-road construction equipment, such as concrete
2004 saws and bulldozers. Emissions from off-road equipment are estimated using the total
2005 operating time of the equipment and the appropriate EF. The operating time is estimated using
2006 the per day average use in hours of each equipment type. Typical operating times for different
2007 types of equipment may be either estimated or taken from CALEEMOD and URBEMIS.
2008 Criteria Pollutant and GHG emissions from each off-road engine may be calculated using the
2009 EFs, based on construction year, provided in Table 4-3 through Table 4-14. Additionally
2010 default horse-powers and load factors for various pieces of off-road equipment can be found in
2011 Table 4-15. Emissions are calculated as follows:

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

Equation 4-5

Where,

2015 **E(Pol)** = Emissions of individual pollutant for all equipment types (lb)

2016 **WD** = Work duration (days)

2017 **EF(Pol)_i** = Emission factor for specific equipment (g/hp-hr)

2018 **H** = Hours worked per day (hr/day)

2019 **N_i** = Number of specific pieces of equipment

2020 **hp** = horsepower of offroad equipment (hp)

2021 **LF** = Load Factor of off-road equipment (unitless)

2022 **i** = Denotes the individual equipment types

2023 **0.002205** = Factor for converting grams to pounds (lb/g)

2024

2025

2026 4.3.3 Vehicle Exhaust (On-Road) Emissions

2027 The following table provides a summary of the on-road vehicle usage for each construction
2028 phase:

2029 **Table 4-2. On-Road Vehicle Usage for Construction**

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

2030

2031

2032 The calculation of on-road vehicle exhaust emissions is the same for all construction phases:

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

Equation 4-6

Where,

2036 **E(Pol)_{Total}** = Total annual emissions of specific pollutant from vehicle exhaust (lb/yr)

2037 **VMT_{Total}** = Total vehicle miles traveled (miles/year)

2038 **EF(Pol)_{Total}** = Total annual emissions of specific pollutant from vehicle exhaust (lb/yr)

2039 **0.002205** = Factor for converting grams to pounds (lb/g)

2040

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

Equation 4-7

2042
2043 Where,

2044 **MIX_i** = Vehicle mix for a specific vehicle category (%). Note that this will vary
2045 across construction phases.

2046 **FERF(Pol)** = Pollutant-specific Fuel Emission Reduction Factor, as applicable (%).
2047 Typically, this is assumed to be 0, but values are provided in the
2048 appropriate section of the latest version of the *Air Emissions Guide for*
2049 *Air Force Mobile Sources*

2050 **i** = Vehicle category identifier (1 = LDGV, 2 = LDDV, etc.)
2051

2052 The challenge in estimating emissions using Equation 4-6 is that the VMT may be difficult to
2053 estimate. The recommended approach to estimating the VMT is to take the product of the total
2054 round trips made and the average miles per trip as shown:

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

Equation 4-8

2055
2056
2057 Where,

2058 **HT** = Average hauling truck round trip commute (miles/trip). **Assume 20 miles/trip**
2059 **if unknown.**
2060

2061
2062 The number of round trips made can now be estimated based on the construction phase. The
2063 procedures for determining the number of trips are outlined in the following sections.
2064

2065 4.3.3.1 Demolition Round Trips

2066 The number of round trips taken by each vehicle during the demolition phase may be estimated
2067 using the demolition volume (product of the building height and area). By using the
2068 demolition volume, the average truck hauling capacity, and applying a volume reduction
2069 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

2070
2071
2072 Where,

2073 **BA** = Area of building to be demolished (ft²)

2074 **BH** = Height of building to be demolished (ft)

2075 **27** = Factor converting ft³ to yd³ (yd³/ft³)

2076 **0.25** = Volume reduction factor (material reduced by 75% to account for air space)

2077 **HC** = Average truck hauling capacity per trip (yd³/trip). Assume 20 yd³/trip if
 2078 unknown.

2079

2080 4.3.3.2 Site Grading (Fill) or Trenching (Cut) Round Trips

2081 To estimate the number of round trips made during the site grading and trenching phase of
 2082 construction, the amount of fill material (Fill) to be hauled to the site and the amount of cut
 2083 material (Cut) to be hauled away from the site must be accounted for. The number of round
 2084 trips may be estimated as shown:

$$2085 \quad \text{Round Trips}_{\text{Fill}} = \text{FILL} \times \frac{1}{\text{HC}}$$

2086

Equation 4-10

$$2087 \quad \text{Round Trips}_{\text{Cut}} = \text{CUT} \times \frac{1}{\text{HC}}$$

2088

Equation 4-11

2089 Where,

2090 **FILL** = Amount of fill material hauled to the site (ft³)

2091 **CUT** = Amount of cut material hauled away from the site (ft³)

2092 **HC** = Average truck hauling capacity per trip (yd³/trip). Assume 20 yd³/trip if
 2093 unknown.

2094

2095 4.3.3.3 Building Construction Material Round Trips

2096 Based on guidance provided by CALEEMOD and URBEMIS, the round trips made during
 2097 building construction are grouped into different general land use categories and estimated as
 2098 follows:

2099

2100 Military Family Housing:

$$2101 \quad \text{Round Trips}_{\text{Multifamily}} = N \times 0.36$$

2102

Equation 4-12

$$2103 \quad \text{Round Trips}_{\text{Single-Family}} = N \times 0.72$$

2104

Equation 4-13

2105

2106 Base Exchange, Commissary, etc.:

$$2107 \quad \text{Round Trips}_{\text{Commercial or Retail}} = \text{CA} \times \frac{1}{1000} \times 0.32$$

2108

Equation 4-14

2109 Offices or Industrial Buildings:

$$2110 \quad \text{Round Trips}_{\text{Office or Industrial}} = CA \times \frac{1}{1000} \times 0.42$$

Equation 4-15

2111

2112 Where,

2113 **N** = Number of units2114 **0.36/0.72** = Factor converting units to trips (trips/unit)2115 **CA** = Construction area (ft²)2116 **1000** = Factor converting ft² to 10³ ft² (10³ ft²/ft²)2117 **0.32/0.42** = Factor converting 10³ ft to trips (trips/10³ ft²)

2118

2119 **4.3.3.4 Paving Round Trips**

2120 Estimating the number of round trips made during paving operations is a function of the
 2121 volume of pavement applied to the surface. The volume used in this calculation is the product
 2122 of the area paved and pavement thickness, which is assumed to be 0.25 ft. The number of
 2123 round trips made during paving operations is calculated as shown:

$$2124 \quad \text{Round Trips}_{\text{Paving}} = PA \times 0.25 \times \frac{1}{27} \times \frac{1}{HC}$$

Equation 4-16

2125

2126 Where,

2127 **PA** = Paving area (ft²)2128 **0.25** = Thickness of paved area (ft)2129 **27** = Factor converting ft³ to yd³ (yd³/ft³)2130 **HC** = Average truck hauling capacity per trip (yd³/trip). **Assume 20 yd³/trip if**
 2131 **unknown.**

2132

2133 **4.3.4 Worker Commute Trip Emissions**

2134 Emissions are generated by the operation of on-road private vehicles to and from the site. As
 2135 with vehicle exhaust emissions, the emissions from workers commuting may be estimated
 2136 using Equation 4-6 but **assumes a vehicle mix (MIX_i) of 50% LDGV and 50% LDGT**. The
 2137 method for estimating VMT from workers commuting is different than the method provided
 2138 for estimating VMT from vehicle exhaust. The VMT estimating methods for each construction
 2139 phase are provided below.

2140

2141 **4.3.4.1 VMT Estimates for Construction Phases Excluding Architectural Coatings**

2142 The process of estimating VMT for demolition, site grading, trenching, excavating, building
 2143 construction, and paving is the same. The recommended method for estimating VMT for
 2144 workers commuting is to first assume that the total number of workers is equal to 125% of the
 2145 total pieces of construction equipment selected for each phase. Based on the number of total

2146 pieces of equipment in use (N_i) in each phase and applying the total workdays, an estimate of
 2147 VMT is possible:

$$2148 \quad VMT = 1 \times WD \times WT \times 1.25 \times \sum_{i=1}^n N_i$$

2149 **Equation 4-17**

2150 Where,

2151 **1** = Number of worker trips per day (trip/day)

2152 **WD** = Work duration (days)

2153 **WT** = Average worker round trip commute (miles/trip). Assume 20 miles/trip if
 2154 unknown.

2155 **1.25** = Factor converting the number of construction equipment to the number of
 2156 workers

2157 **N_i** = Number of total pieces of construction equipment in use

2158

2159 4.3.4.2 VMT Estimates for Architectural Coating

2160 Worker commute trips associated with architectural coating are assumed to equal the number
 2161 of single-day trips one worker, that operates at a rate of 800 ft²/day, would need to commute to
 2162 complete painting the area to be coated:

$$2163 \quad VMT_{Arch.Painting} = \frac{(1 \times WT \times SA)}{800}$$

2164 **Equation 4-18**

2165 Where,

2166 **1** = Number of worker trips per day (trip/day)

2167 **WT** = Average worker round trip commute (miles/trip). Assume 20 miles/trip if
 2168 **unknown.**

2169 **SA** = Area of surface to be coated (ft²)

2170 **800** = Assumed worker rate of paint application (ft²/day)

2171

2172 4.3.5 Vendor Trip Emissions

2173 Vendor trips represent the on-road vehicle trips needed to bring building supplies to the
 2174 worksite **during the Building Construction phase only.** Vendor trip emissions are calculated
 2175 using Equation 4-8 and the **assumption that the hauling truck commute is about 40 miles**
 2176 **per trip, if unknown.**

2177

2178 Vendor trips are calculated using information provided by the Sacramento Metropolitan Air
 2179 Quality Management District:

2180

2181 Military Family Housing:

$$2182 \quad \text{Round Trips}_{\text{Multifamily/Single-Family}} = N \times 0.11$$

2183 Equation 4-19

2184

2185 Base Exchange or Commissary:

$$2186 \quad \text{Round Trips}_{\text{Commercial or Retail}} = CA \times \frac{1}{1000} \times 0.05$$

2187 Equation 4-20

2188

2189 Offices or Industrial Buildings:

$$2190 \quad \text{Round Trips}_{\text{Office or Industrial}} = CA \times \frac{1}{1000} \times 0.38$$

2191 Equation 4-21

2192 Where,

2193 **N** = Number of units

2194 **CA** = Construction area (ft²)

2195 **0.11/0.05/0.38** = Factor converting units to trips (trip/unit)

2196

2197 Finally, emissions from vendor trips are calculated using Equation 4-6 assuming the vehicle
2198 mix is 100% Heavy-Duty Diesel Vehicles (HDDV).

2199

2200 4.3.6 Off-Gassing Emissions

2201 Off-Gassing occurs **during the Architectural Coatings and Paving phases** due to
2202 evaporation of solvents contained in surface coatings and asphalt. Emissions from these phases
2203 are calculated differently and described below.

2204

2205 4.3.6.1 Architectural Coatings

2206 Separate procedures are used to estimate evaporative emissions from application of residential
2207 and non-residential architectural coatings. Emissions are based on the total surface area to be
2208 coated (ft²), the coating coverage (ft²/gal), and VOC content (g/L) of the coating.

2209

2210 Surface Area Size

2211 The surface area to be painted (SA) is estimated using the following equations:

2212

2213 Military Family Housing:

$$2214 \quad SA_{\text{Multifamily}} = N \times 850 \times 2.7$$

2215 Equation 4-22

$$2216 \quad SA_{Single-Family} = N \times 1800 \times 2.7$$

2217 **Equation 4-23**

2218 Where,

2219 **N** = Number of units

2220 **850** = Factor converting units to square feet (ft²/units)

2221 **1800** = Factor converting units to square feet (ft²/units)

2222 **2.7** = Factor converting total area to coated area

2223

2224 All Other Buildings:

$$2225 \quad SA_{Non-Residential} = \sqrt{BA} \times 4 \times BH$$

2226 **Equation 4-24**

2227 Where,

2228 **BA** = Total building square footage (ft²)

2229 **BH** = Building height (ft)

2230 **4** = Number of walls, assuming a square shaped building

2231

2232 This equation assumes the length and width of the building are equal. If the total building
2233 square footage is unknown, this value can be calculated by multiplying the length of the
2234 building by the width of the building.

2235

2236 **Emission Factor:**

2237 For architectural coatings, California has calculated a statewide average VOC content of 250
2238 grams VOC per liter of paint. Per CALEEMOD 2022, an average coating coverage of 180
2239 square feet per gallon is assumed. A VOC EF may be derived as shown:

$$2240 \quad EF(VOC) = SA \times \frac{250 \text{ g VOCs}}{1 \text{ L Paint}} \times \frac{1 \text{ gal Paint}}{180 \text{ ft}^2} \times \frac{1 \text{ lb}}{454 \text{ g}} \times \frac{3.785 \text{ L}}{1 \text{ gal}} = 0.0116 \frac{\text{lb}}{\text{ft}^2}$$

2241

2242 **Emissions Estimate:**

2243 Using the surface area and EF derived above, the total VOC emissions can be estimated as
2244 follows:

$$2245 \quad E(VOC) = SA \times 0.0116$$

2246 **Equation 4-25**

2247

2248 **4.3.6.2 Paving (Asphalt)**

2249 VOC emissions are estimated by multiplying the area to be paved by the asphalt EF of 2.62
2250 pounds per acre (Sacramento Metropolitan Air Quality Management District 1994). VOC
2251 emissions are estimated using the following formula:

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

Equation 4-26

2252
2253
2254 Where,

2255 PA = Paving area (ft²)

2256 2.62 = Emission factor (lb/acre)

2257 43,560 = Factor converting square feet to acres (ft²/acre)

2258

2259 4.4 Information Resources

2260 Construction operations may be performed either by Civil Engineering or by a contracted
2261 company. Base Civil Engineering should be able to provide information needed to estimate
2262 emissions and should be contacted for all pertinent data. Emissions may be estimated through
2263 several software programs such as ACAM. Refer to the supporting documentation for these
2264 programs for assumptions made and guidance in estimating emissions.

2265

2266 4.5 Example Problem

2267 During calendar year 2020, a USAF Base (located in Alabama – 600 feet above sea level)
2268 contracted a company to demolish an existing building. The building was described as 5,000
2269 square feet and 18 feet tall on a one-acre lot. The demolition took 4 weeks to complete with a
2270 typical 8-hr, 5-day work week. The contractor stated that during demolition, two 120
2271 horsepower (hp) tractors, one 250 hp rubber tire dozer, and two 50 hp concrete saws were used.
2272 The contractor's best estimate was that the tractors, dozer, and saws operated for 6, 4, and 5
2273 hours per day on average. Calculate the PM₁₀ emissions from the demolition of this building.

2274

2275 **Step 1 – Determine the emission classes associated with demolition.** Looking at Table 4-1,
2276 the classes associated with demolition include: **fugitive dust, construction exhaust, vehicle**
2277 **exhaust, and worker trips.**

2278

2279 **Step 2 – Calculate fugitive dust emissions.** Using the building area, height, and Equation
2280 4-3, PM₁₀ emissions are calculated as shown:

$$2281 \quad E(PM_{10}) = 0.00042 \times BA \times BH$$

$$2282 \quad E(PM_{10})_{Fugitive\ Dust} = 0.00042 \frac{lb}{ft^3} \times 5000 ft^2 \times 18 ft$$

$$2283 \quad E(PM_{10})_{Fugitive\ Dust} = 0.00042 \frac{lb}{ft^3} \times 90000 ft^3 = 37.8 lb$$

2284

2285 **Step 3 – Calculate the workdays.** The problem stated that the process took four 5-day work
 2286 weeks to complete. The number of workdays is estimated as follows:

$$2287 \quad WD = 28 \text{ days} \times \frac{5 \text{ days}}{7 \text{ days}} = 20 \text{ days}$$

2288

2289 **Step 4 – Select and record the appropriate EFs.** Construction equipment EFs for 220 are
 2290 provided in Table 4-3. The PM₁₀ EFs for the tractor, dozer, and saw are **0.203, 0.201, and**
 2291 **0.137 g/hp-hr**, respectively.

2292

2293 **Step 5 – Calculate construction exhaust emissions.** Using the EFs provided in Step 4, the
 2294 workdays estimated in Step 3, the data in the problem statement, and Equation 4-5, the
 2295 emissions from construction exhaust are calculated as follows:

$$2296 \quad E(Pol) = \sum_{i=1}^n [WD \times EF(Pol)_i \times H \times N_i \times hp \times LF]$$

$$2297 \quad E(PM_{10})_{Construction\ Exhaust}$$

$$2298 \quad = \left[\left(20 \text{ days} \times 0.203 \frac{g}{hp-hr} \times 6 \frac{hr}{day} \times 2 \times 38 \text{ hp} \times .44 \right) \right.$$

$$2299 \quad + \left(20 \text{ days} \times 0.201 \frac{g}{hp-hr} \times 4 \frac{hr}{day} \times 1 \times 367 \text{ hp} \times .40 \right)$$

$$2300 \quad \left. + \left(20 \text{ days} \times 0.137 \frac{g}{hp-hr} \times 5 \frac{hr}{day} \times 2 \times 33 \text{ hp} \times .73 \right) \right]$$

$$2301 \quad E(PM_{10})_{Construction\ Exhaust} = [(1851.4 \text{ g}) + (4,721.1 \text{ g}) + (660.1 \text{ g})] = 3,835.21 \text{ g}$$

2302

$$2303 \quad E(PM_{10})_{Construction\ Exhaust} = 3,835.21 \text{ g} \times 0.002205 \frac{lb}{g} = 8.46 \text{ lb}$$

2304

2305 **Step 6 – Calculate the number of round trips made that contributed to vehicle exhaust.**

2306 The demolition phase of construction also results in vehicle exhaust emissions that must be
 2307 calculated. The first step in making this calculation is to determine the number of round trips
 2308 made. Using the area and height of the demolished building and assuming the truck hauling
 2309 capacity is 20 yd³/trip, an estimate of the number of round trips may be calculated using
 2310 Equation 4-9:

$$2311 \quad Round\ Trips = BA \times BH \times \frac{1}{27} \times 0.25 \times \frac{1}{HC}$$

$$2312 \quad Round\ Trips = 5000 \text{ ft}^2 \times 18 \text{ ft} \times \frac{1 \text{ yd}^3}{27 \text{ ft}^3} \times 0.25 \times \frac{1 \text{ trip}}{20 \text{ yd}^3}$$

$$2313 \quad \text{Round Trips} = 90000 \frac{ft^3}{ft^3} \times \frac{1 \text{ yd}^3}{27 \text{ ft}^3} \times 0.25 \times \frac{1 \text{ trip}}{20 \text{ yd}^3}$$

$$2314 \quad \text{Round Trips} = 3333.33 \frac{yd^3}{yd^3} \times 0.25 \times \frac{1 \text{ trip}}{20 \text{ yd}^3}$$

$$2315 \quad \text{Round Trips} = 166.67 \text{ trip} \times 0.25 = \mathbf{42 \text{ trips}}$$

2316

2317 **Step 7 – Calculate the VMT.** Using the number of round trips made as estimated by Step 6
 2318 and assuming the average hauling truck commute is 20 miles/trip, the VMT may be calculated
 2319 using Equation 4-8:

$$2320 \quad VMT = \text{Round Trips} \times HT$$

$$2321 \quad VMT = 42 \text{ trips} \times 20 \frac{\text{miles}}{\text{trip}} = 840 \text{ miles}$$

2322

2323 **Step 8 – Select and record the appropriate EF.** The vehicle mix for vehicle exhaust
 2324 emissions is assumed to be 100% HDDV. For CY2023, the PM₁₀ EF in Alabama, according to
 2325 the 2023 *Air Emissions Guide for Air Force Mobile Sources*, is **0.007 g/mile**.

2326

2327 **Step 9 – Calculate vehicle exhaust emissions.** Using the EF recorded in Step 8, the VMT
 2328 calculated in Step 7, and Equation 4-6, the PM₁₀ emissions from vehicle exhaust is calculated
 2329 as follows:

$$2330 \quad E(Pol) = VMT \times EF(Pol) \times 0.002205$$

$$2331 \quad E(PM_{10})_{\text{Vehicle Emissions}} = 840 \text{ miles} \times 0.007 \frac{\text{g}}{\text{mile}} \times 0.002205 \frac{\text{lb}}{\text{g}}$$

$$2332 \quad E(PM_{10})_{\text{Vehicle emissions}} = \mathbf{0.013 \text{ lb}}$$

2333

2334 **Step 10 – Estimate the VMT for worker commute.** Assuming an average worker commute
 2335 of 20 miles/trip, the workdays estimated in Step 3, and Equation 4-17, the VMT is calculated
 2336 as follows:

$$2337 \quad VMT = 1 \times WD \times WT \times 1.25 \times \sum_{i=1}^n N_i$$

$$2338 \quad VMT = 1 \frac{\text{trip}}{\text{day}} \times 20 \text{ days} \times 20 \frac{\text{miles}}{\text{trip}} \times 1.25 \times 4 = \mathbf{2,000 \text{ miles}}$$

2339

2340 **Step 11 – Select and record the appropriate EFs.** Assuming a mix of LDGV and LDGT for
 2341 worker vehicle types, the EFs for PM₁₀ from the 2023 *Air Emissions Guide for Air Force*
 2342 *Mobile Sources* are **0.004 and 0.005 g/miles, respectively.**

2343
 2344 **Step 12 – Calculate the composite EF.** Assuming a vehicle mix of 50% LDGV and 50%
 2345 LDGT, a FERF of 0, and the EFs recorded in Step 11, the composite EF is calculated using
 2346 Equation 4-7 as follows:

$$2347 \quad EF(Pol)_{Total} = \sum_{i=1}^n \left\{ \left(\frac{MIX_i}{100} \right) \times EF(Pol)_i \times \left[1 - \frac{FERF(Pol)}{100} \right] \right\}$$

$$2348 \quad EF(PM_{10}) = \sum \left\{ \left(\frac{50\%}{100\%} \right) \times 0.004 \frac{g}{mile} \times \left[1 - \frac{0\%}{100\%} \right] \right\} +$$

$$2349 \quad \left\{ \left(\frac{50\%}{100\%} \right) \times 0.005 \frac{g}{mile} \times \left[1 - \frac{0\%}{100\%} \right] \right\}$$

$$2350 \quad EF(PM_{10}) = \sum \left\{ 0.5 \times 0.004 \frac{g}{mile} \right\} + \left\{ 0.5 \times 0.005 \frac{g}{mile} \right\} = \mathbf{0.0045 \frac{g}{mile}}$$

2351
 2352 **Step 13 – Calculate emissions from worker trips.** Using Equation 4-6, the VMT calculated
 2353 in Step 10, and the EF calculated in Step 12, the PM₁₀ emissions are calculated as follows:

$$2354 \quad E(Pol)_{Total} = VMT_{Total} \times EF(Pol)_{Total} \times 0.002205$$

$$2355 \quad E(PM_{10})_{Worker Trips} = 2000 \text{ miles} \times 0.0045 \frac{g}{mile} \times 0.002205 \frac{lb}{g} = \mathbf{0.01764 lb}$$

2356
 2357
 2358 **Step 14 – Calculate total PM₁₀.** The final step is to sum the PM₁₀ emissions from each class
 2359 comprising the demolition phase of construction using Equation 4-2:

$$2360 \quad E(Pol)_i = E(Pol)_{Fugitive Dust} + E(Pol)_{Construction Exhaust} + E(Pol)_{Vehicle Emissions}$$

$$2361 \quad + E(Pol)_{Worker Trips} + E(Pol)_{Vendor Trips} + E(Pol)_{Off-Gasing}$$

$$2362 \quad E(PM_{10})_{Demolition} = 37.8 \text{ lb} + 12.16 \text{ lb} + 0.307 \text{ lb} + 0.0309 \text{ lb} + 0 + 0$$

$$2363 \quad \boxed{E(PM_{10})_{Demolition} = \mathbf{46.3 lb}}$$

2364

2365

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

Equipment	Emission Factor (g/hp-hr)					
	NO _x	CO	SO _x	VOC	PM ₁₀	PM _{2.5}
Aerial Lifts	2.895	3.120	0.005	0.162	0.023	0.021
Air Compressors	3.976	4.914	0.007	0.623	0.157	0.144
Bore/Drill Rigs	2.068	3.296	0.005	0.178	0.083	0.077
Cement and Mortar Mixers	4.206	3.259	0.009	0.555	0.165	0.151
Concrete/Industrial Saws	3.862	4.426	0.007	0.507	0.137	0.126
Cranes	2.232	1.703	0.005	0.213	0.089	0.082
Crawler Tractors	4.682	3.852	0.005	0.548	0.367	0.338
Crushing/Proc. Equipment	4.732	267.506	0.012	188.517	3.266	2.468
Dumpers/Tenders	4.366	2.358	0.007	0.571	0.163	0.150
Excavators	3.587	4.226	0.005	0.448	0.139	0.128
Forklifts	2.981	3.630	0.005	0.316	0.182	0.168
Generator Sets	4.402	2.894	0.008	0.550	0.184	0.170
Graders	3.506	3.420	0.005	0.385	0.193	0.177
Off-Highway Tractors	3.991	4.842	0.005	0.656	0.203	0.187
Off-Highway Trucks	1.325	1.211	0.005	0.186	0.048	0.044
Other Construction Equipment	3.539	3.587	0.005	0.381	0.240	0.221
Other General Industrial Equipment	3.989	4.877	0.005	0.601	0.194	0.178
Other Material Handling Equipment	2.047	3.449	0.005	0.188	0.080	0.074
Pavers	2.711	3.396	0.005	0.233	0.137	0.126
Paving Equipment	2.584	3.452	0.005	0.247	0.129	0.119
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.450	3.287	0.009	0.538	0.189	0.174
Pumps	4.398	3.025	0.008	0.588	0.191	0.176
Rollers	3.911	4.241	0.005	0.659	0.211	0.194
Rough Terrain Forklifts	1.836	3.217	0.005	0.125	0.045	0.041
Rubber Tired Dozers	4.462	3.582	0.005	0.445	0.201	0.185
Rubber Tired Loaders	2.211	3.295	0.005	0.271	0.119	0.109
Scrapers	2.474	1.761	0.005	0.237	0.095	0.087
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	2.031	3.260	0.005	0.153	0.069	0.063
Surfacing Equipment	1.214	1.067	0.005	0.114	0.046	0.043
Sweepers/Scrubbers	4.124	4.967	0.005	0.759	0.248	0.228
Tractors/Loaders/Backhoes	2.317	3.487	0.005	0.225	0.111	0.102
Trenchers	3.949	4.291	0.005	0.640	0.219	0.202
Welders	3.891	4.596	0.007	0.577	0.151	0.139

2366

2367

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

2368

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

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

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

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

Equipment	Emission Factor (g/hp-hr)					
	NO _x	CO	SO _x	VOC ^a	PM ₁₀	PM _{2.5}
Aerial Lifts	2.88	3.09	0.01	0.15	0.02	0.02
Air Compressors	3.76	4.85	0.01	0.54	0.12	0.11
Bore/Drill Rigs	1.74	3.25	0.00	0.14	0.05	0.05
Cement and Mortar Mixers	4.20	3.26	0.01	0.55	0.16	0.15
Concrete/Industrial Saws	3.63	4.35	0.01	0.44	0.10	0.09
Cranes	1.95	1.66	0.00	0.20	0.08	0.07
Crawler Tractors	3.88	3.75	0.00	0.44	0.28	0.26
Crushing/Proc. Equipment	4.73	267.50	0.01	188.50	3.27	2.47
Dumpers/Tenders	4.37	2.36	0.01	0.57	0.16	0.15
Excavators	3.45	4.21	0.01	0.40	0.11	0.10
Forklifts	2.55	3.60	0.00	0.27	0.13	0.12
Generator Sets	4.35	2.87	0.01	0.54	0.18	0.16
Graders	2.86	3.42	0.00	0.34	0.16	0.15
Off-Highway Tractors	3.68	4.61	0.01	0.52	0.14	0.13
Off-Highway Trucks	1.09	1.17	0.00	0.18	0.04	0.04
Other Construction Equipment	2.89	3.51	0.00	0.30	0.17	0.16
Other General Industrial Equipment	3.71	4.67	0.01	0.49	0.14	0.13
Other Material Handling Equipment	1.96	3.46	0.00	0.18	0.07	0.06
Pavers	2.65	3.45	0.00	0.25	0.14	0.13
Paving Equipment	2.22	3.42	0.00	0.20	0.09	0.08
Plate Compactors	4.14	3.47	0.01	0.55	0.16	0.15
Pressure Washers	4.38	3.26	0.01	0.53	0.18	0.17
Pumps	4.33	3.00	0.01	0.57	0.18	0.17
Rollers	3.68	4.11	0.01	0.57	0.17	0.15
Rough Terrain Forklifts	1.69	3.22	0.00	0.12	0.04	0.03
Rubber Tired Dozers	3.51	2.90	0.00	0.37	0.15	0.14
Rubber Tired Loaders	1.60	3.28	0.00	0.23	0.08	0.08
Scrapers	1.91	1.58	0.00	0.20	0.07	0.07
Signal Boards	4.14	3.47	0.01	0.55	0.16	0.15
Skid Steer Loaders	1.86	3.25	0.00	0.14	0.06	0.05
Surfacing Equipment	0.99	1.07	0.00	0.11	0.04	0.03
Sweepers/Scrubbers	3.85	4.76	0.01	0.62	0.19	0.18
Tractors/Loaders/Backhoes	2.01	3.48	0.00	0.20	0.08	0.07
Trenchers	3.65	4.11	0.01	0.54	0.16	0.15
Welders	3.68	4.52	0.01	0.50	0.11	0.10

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

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

Equipment	Emission Factor (g/hp-hr)					
	NO _x	CO	SO _x	VOC ^a	PM ₁₀	PM _{2.5}
Aerial Lifts	2.874	3.075	0.005	0.152	0.021	0.019
Air Compressors	3.646	4.822	0.007	0.512	0.099	0.091
Bore/Drill Rigs	1.639	3.253	0.005	0.128	0.040	0.037
Cement and Mortar Mixers	4.198	3.255	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.526	4.315	0.007	0.413	0.085	0.078
Cranes	1.837	1.637	0.005	0.198	0.075	0.069
Crawler Tractors	3.631	3.725	0.005	0.414	0.251	0.231
Crushing/Proc. Equipment	4.725	267.313	0.012	188.498	3.263	2.465
Dumpers/Tenders	4.358	2.354	0.007	0.570	0.163	0.150
Excavators	3.407	4.221	0.005	0.393	0.099	0.091
Forklifts	2.342	3.579	0.005	0.246	0.112	0.103
Generator Sets	4.324	2.860	0.008	0.539	0.174	0.160
Graders	2.528	3.397	0.005	0.313	0.140	0.129
Off-Highway Tractors	3.617	4.600	0.005	0.490	0.126	0.116
Off-Highway Trucks	1.011	1.178	0.005	0.176	0.036	0.033
Other Construction Equipment	2.734	3.504	0.005	0.282	0.158	0.145
Other General Industrial Equipment	3.588	4.594	0.005	0.453	0.113	0.104
Other Material Handling Equipment	1.906	3.450	0.005	0.177	0.060	0.055
Pavers	2.533	3.431	0.005	0.237	0.129	0.119
Paving Equipment	2.065	3.403	0.005	0.190	0.080	0.074
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.349	3.253	0.009	0.526	0.178	0.163
Pumps	4.309	2.993	0.008	0.569	0.177	0.163
Rollers	3.614	4.093	0.005	0.542	0.154	0.142
Rough Terrain Forklifts	1.643	3.220	0.005	0.115	0.033	0.030
Rubber Tired Dozers	3.223	2.726	0.005	0.353	0.142	0.131
Rubber Tired Loaders	1.398	3.293	0.005	0.211	0.073	0.067
Scrapers	1.741	1.539	0.005	0.196	0.068	0.062
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.807	3.245	0.005	0.134	0.051	0.047
Surfacing Equipment	0.834	1.053	0.005	0.096	0.030	0.027
Sweepers/Scrubbers	3.759	4.731	0.005	0.584	0.171	0.157
Tractors/Loaders/Backhoes	1.885	3.481	0.005	0.184	0.063	0.058
Trenchers	3.536	4.047	0.005	0.506	0.141	0.130
Welders	3.570	4.493	0.007	0.465	0.095	0.088

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

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

Equipment	Emission Factor (g/hp-hr)					
	NO _x	CO	SO _x	VOC ^a	PM ₁₀	PM _{2.5}
Aerial Lifts	2.870	3.070	0.005	0.151	0.020	0.019
Air Compressors	3.538	4.790	0.007	0.482	0.081	0.075
Bore/Drill Rigs	1.589	3.273	0.005	0.129	0.035	0.033
Cement and Mortar Mixers	4.198	3.255	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.430	4.291	0.007	0.390	0.071	0.065
Cranes	1.748	1.629	0.005	0.195	0.072	0.066
Crawler Tractors	3.310	3.690	0.005	0.372	0.215	0.198
Crushing/Proc. Equipment	4.722	267.383	0.012	188.489	3.263	2.465
Dumpers/Tenders	4.361	2.355	0.007	0.570	0.163	0.150
Excavators	3.367	4.216	0.005	0.378	0.089	0.082
Forklifts	2.152	3.568	0.005	0.228	0.092	0.085
Generator Sets	4.305	2.852	0.008	0.537	0.172	0.158
Graders	2.284	3.406	0.005	0.295	0.127	0.117
Off-Highway Tractors	3.536	4.569	0.005	0.453	0.107	0.098
Off-Highway Trucks	0.965	1.179	0.005	0.176	0.034	0.031
Other Construction Equipment	2.500	3.484	0.005	0.252	0.132	0.122
Other General Industrial Equipment	3.525	4.597	0.005	0.436	0.099	0.091
Other Material Handling Equipment	1.853	3.460	0.005	0.176	0.056	0.051
Pavers	2.450	3.438	0.005	0.229	0.119	0.110
Paving Equipment	2.016	3.403	0.005	0.183	0.075	0.069
Plate Compactors	4.143	3.470	0.009	0.547	0.162	0.149
Pressure Washers	4.331	3.250	0.009	0.524	0.175	0.161
Pumps	4.288	2.986	0.008	0.565	0.173	0.160
Rollers	3.577	4.105	0.005	0.529	0.146	0.134
Rough Terrain Forklifts	1.619	3.216	0.005	0.113	0.032	0.029
Rubber Tired Dozers	3.091	2.656	0.005	0.343	0.135	0.125
Rubber Tired Loaders	1.240	3.304	0.005	0.200	0.063	0.058
Scrapers	1.609	1.522	0.005	0.191	0.063	0.058
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.753	3.243	0.005	0.129	0.047	0.043
Surfacing Equipment	0.778	1.054	0.005	0.094	0.027	0.025
Sweepers/Scrubbers	3.671	4.690	0.005	0.541	0.149	0.137
Tractors/Loaders/Backhoes	1.807	3.487	0.005	0.177	0.054	0.050
Trenchers	3.445	3.992	0.005	0.467	0.122	0.112
Welders	3.466	4.461	0.007	0.435	0.079	0.073

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

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

Equipment	Emission Factor (g/hp-hr)					
	NO _x	CO	SO _x	VOC ^a	PM ₁₀	PM _{2.5}
Aerial Lifts	2.871	3.075	0.005	0.151	0.020	0.018
Air Compressors	3.440	4.760	0.007	0.457	0.065	0.060
Bore/Drill Rigs	1.597	3.288	0.005	0.132	0.035	0.033
Cement and Mortar Mixers	4.197	3.256	0.009	0.553	0.163	0.150
Concrete/Industrial Saws	3.344	4.271	0.007	0.370	0.058	0.053
Cranes	1.601	1.628	0.005	0.187	0.066	0.061
Crawler Tractors	3.059	3.669	0.005	0.340	0.186	0.171
Crushing/Proc. Equipment	4.723	267.290	0.012	188.489	3.262	2.464
Dumpers/Tenders	4.362	2.356	0.007	0.571	0.163	0.150
Excavators	3.339	4.222	0.005	0.366	0.081	0.075
Forklifts	2.032	3.565	0.005	0.216	0.079	0.072
Generator Sets	4.289	2.846	0.008	0.535	0.170	0.156
Graders	2.086	3.418	0.005	0.281	0.116	0.106
Off-Highway Tractors	3.502	4.600	0.005	0.442	0.096	0.089
Off-Highway Trucks	0.889	1.170	0.005	0.174	0.032	0.029
Other Construction Equipment	2.433	3.486	0.005	0.245	0.124	0.114
Other General Industrial Equipment	3.447	4.548	0.005	0.409	0.084	0.077
Other Material Handling Equipment	1.789	3.479	0.005	0.174	0.050	0.046
Pavers	2.338	3.435	0.005	0.216	0.105	0.097
Paving Equipment	1.883	3.377	0.005	0.163	0.058	0.053
Plate Compactors	4.143	3.471	0.009	0.547	0.162	0.149
Pressure Washers	4.309	3.243	0.009	0.521	0.173	0.159
Pumps	4.270	2.980	0.008	0.561	0.171	0.157
Rollers	3.509	4.084	0.005	0.501	0.132	0.121
Rough Terrain Forklifts	1.576	3.208	0.005	0.109	0.029	0.027
Rubber Tired Dozers	3.041	2.663	0.005	0.342	0.134	0.123
Rubber Tired Loaders	1.098	3.317	0.005	0.191	0.054	0.050
Scrapers	1.493	1.500	0.005	0.185	0.059	0.054
Signal Boards	4.143	3.470	0.009	0.547	0.162	0.149
Skid Steer Loaders	1.712	3.245	0.005	0.126	0.043	0.039
Surfacing Equipment	0.699	1.057	0.005	0.091	0.025	0.023
Sweepers/Scrubbers	3.613	4.688	0.005	0.517	0.133	0.123
Tractors/Loaders/Backhoes	1.749	3.496	0.005	0.173	0.048	0.044
Trenchers	3.399	3.997	0.005	0.447	0.110	0.102
Welders	3.371	4.432	0.007	0.409	0.064	0.059

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

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

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

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.936	0.024	0.005	586.922
Air Compressors	570.276	0.023	0.005	568.326
Bore/Drill Rigs	525.117	0.021	0.004	523.321
Cement and Mortar Mixers	572.343	0.023	0.005	570.386
Concrete/Industrial Saws	577.273	0.023	0.005	575.299
Cranes	529.326	0.021	0.004	527.516
Crawler Tractors	530.723	0.021	0.004	528.908
Crushing/Proc. Equipment	434.447	0.018	0.004	432.907
Dumpers/Tenders	574.668	0.023	0.005	572.703
Excavators	588.896	0.024	0.005	586.882
Forklifts	528.905	0.021	0.004	527.097
Generator Sets	570.268	0.023	0.005	568.318
Graders	531.813	0.021	0.004	529.994
Off-Highway Tractors	587.708	0.024	0.005	585.698
Off-Highway Trucks	530.383	0.021	0.004	528.569
Other Construction Equipment	530.064	0.021	0.004	528.251
Other General Industrial Equipment	590.205	0.024	0.005	588.186
Other Material Handling Equipment	530.468	0.021	0.004	528.653
Pavers	527.588	0.021	0.004	525.783
Paving Equipment	530.544	0.021	0.004	528.729
Plate Compactors	570.301	0.023	0.005	568.351
Pressure Washers	580.528	0.023	0.005	578.543
Pumps	570.237	0.023	0.005	568.287
Rollers	588.845	0.024	0.005	586.831
Rough Terrain Forklifts	530.248	0.021	0.004	528.435
Rubber Tired Dozers	534.040	0.022	0.004	532.214
Rubber Tired Loaders	528.131	0.021	0.004	526.324
Scrapers	530.875	0.021	0.004	529.060
Signal Boards	570.250	0.023	0.005	568.299
Skid Steer Loaders	529.635	0.021	0.004	527.823
Surfacing Equipment	529.659	0.021	0.004	527.847
Sweepers/Scrubbers	589.193	0.024	0.005	587.177
Tractors/Loaders/Backhoes	531.565	0.021	0.004	529.747
Trenchers	590.099	0.024	0.005	588.081
Welders	570.242	0.023	0.005	568.291

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

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

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.917	0.024	0.005	586.903
Air Compressors	570.311	0.023	0.005	568.361
Bore/Drill Rigs	523.223	0.021	0.004	521.434
Cement and Mortar Mixers	572.123	0.023	0.005	570.167
Concrete/Industrial Saws	576.878	0.023	0.005	574.905
Cranes	529.342	0.021	0.004	527.532
Crawler Tractors	530.528	0.021	0.004	528.713
Crushing/Proc. Equipment	434.593	0.018	0.004	433.053
Dumpers/Tenders	574.985	0.023	0.005	573.018
Excavators	589.332	0.024	0.005	587.317
Forklifts	528.848	0.021	0.004	527.040
Generator Sets	570.265	0.023	0.005	568.315
Graders	531.990	0.022	0.004	530.170
Off-Highway Tractors	587.573	0.024	0.005	585.564
Off-Highway Trucks	529.574	0.021	0.004	527.763
Other Construction Equipment	530.267	0.021	0.004	528.454
Other General Industrial Equipment	590.170	0.024	0.005	588.151
Other Material Handling Equipment	530.509	0.021	0.004	528.694
Pavers	528.138	0.021	0.004	526.332
Paving Equipment	529.927	0.021	0.004	528.115
Plate Compactors	570.303	0.023	0.005	568.353
Pressure Washers	580.459	0.023	0.005	578.474
Pumps	570.253	0.023	0.005	568.303
Rollers	588.812	0.024	0.005	586.798
Rough Terrain Forklifts	530.324	0.021	0.004	528.511
Rubber Tired Dozers	534.029	0.022	0.004	532.203
Rubber Tired Loaders	528.138	0.021	0.004	526.332
Scrapers	530.783	0.021	0.004	528.968
Signal Boards	570.254	0.023	0.005	568.303
Skid Steer Loaders	529.983	0.021	0.004	528.170
Surfacing Equipment	529.528	0.021	0.004	527.717
Sweepers/Scrubbers	589.022	0.024	0.005	587.008
Tractors/Loaders/Backhoes	531.752	0.021	0.004	529.933
Trenchers	589.921	0.024	0.005	587.904
Welders	570.240	0.023	0.005	568.290

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

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

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.914	0.024	0.005	586.900
Air Compressors	570.313	0.023	0.005	568.363
Bore/Drill Rigs	524.360	0.021	0.004	522.567
Cement and Mortar Mixers	572.132	0.023	0.005	570.175
Concrete/Industrial Saws	576.987	0.023	0.005	575.013
Cranes	529.395	0.021	0.004	527.585
Crawler Tractors	530.285	0.021	0.004	528.471
Crushing/Proc. Equipment	434.326	0.018	0.004	432.786
Dumpers/Tenders	574.846	0.023	0.005	572.880
Excavators	589.153	0.024	0.005	587.138
Forklifts	528.917	0.021	0.004	527.108
Generator Sets	570.273	0.023	0.005	568.322
Graders	533.017	0.022	0.004	531.194
Off-Highway Tractors	588.164	0.024	0.005	586.153
Off-Highway Trucks	530.401	0.021	0.004	528.587
Other Construction Equipment	529.554	0.021	0.004	527.743
Other General Industrial Equipment	590.044	0.024	0.005	588.026
Other Material Handling Equipment	530.593	0.021	0.004	528.778
Pavers	528.344	0.021	0.004	526.537
Paving Equipment	529.497	0.021	0.004	527.686
Plate Compactors	570.357	0.023	0.005	568.406
Pressure Washers	579.811	0.023	0.005	577.829
Pumps	570.194	0.023	0.005	568.244
Rollers	588.916	0.024	0.005	586.902
Rough Terrain Forklifts	530.541	0.021	0.004	528.726
Rubber Tired Dozers	533.998	0.022	0.004	532.172
Rubber Tired Loaders	527.966	0.021	0.004	526.161
Scrapers	530.758	0.021	0.004	528.942
Signal Boards	570.252	0.023	0.005	568.302
Skid Steer Loaders	530.187	0.021	0.004	528.374
Surfacing Equipment	528.930	0.021	0.004	527.121
Sweepers/Scrubbers	588.873	0.024	0.005	586.859
Tractors/Loaders/Backhoes	531.681	0.021	0.004	529.863
Trenchers	589.965	0.024	0.005	587.948
Welders	570.251	0.023	0.005	568.301

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

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

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.914	0.024	0.005	586.900
Air Compressors	570.237	0.023	0.005	568.287
Bore/Drill Rigs	526.884	0.021	0.004	525.082
Cement and Mortar Mixers	572.120	0.023	0.005	570.163
Concrete/Industrial Saws	576.328	0.023	0.005	574.357
Cranes	529.271	0.021	0.004	527.461
Crawler Tractors	530.443	0.021	0.004	528.629
Crushing/Proc. Equipment	433.976	0.018	0.004	432.438
Dumpers/Tenders	573.566	0.023	0.005	571.605
Excavators	589.043	0.024	0.005	587.029
Forklifts	528.906	0.021	0.004	527.097
Generator Sets	570.277	0.023	0.005	568.327
Graders	532.637	0.022	0.004	530.815
Off-Highway Tractors	588.175	0.024	0.005	586.163
Off-Highway Trucks	530.984	0.021	0.004	529.168
Other Construction Equipment	529.352	0.021	0.004	527.541
Other General Industrial Equipment	589.895	0.024	0.005	587.877
Other Material Handling Equipment	530.550	0.021	0.004	528.736
Pavers	527.608	0.021	0.004	525.804
Paving Equipment	529.517	0.021	0.004	527.706
Plate Compactors	570.287	0.023	0.005	568.337
Pressure Washers	579.712	0.023	0.005	577.730
Pumps	570.261	0.023	0.005	568.310
Rollers	588.928	0.024	0.005	586.914
Rough Terrain Forklifts	530.704	0.021	0.004	528.889
Rubber Tired Dozers	534.378	0.022	0.004	532.550
Rubber Tired Loaders	528.221	0.021	0.004	526.415
Scrapers	530.669	0.021	0.004	528.854
Signal Boards	570.252	0.023	0.005	568.302
Skid Steer Loaders	530.435	0.021	0.004	528.621
Surfacing Equipment	529.628	0.021	0.004	527.817
Sweepers/Scrubbers	588.672	0.024	0.005	586.659
Tractors/Loaders/Backhoes	531.525	0.021	0.004	529.707
Trenchers	590.112	0.024	0.005	588.094
Welders	570.241	0.023	0.005	568.291

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

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

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.915	0.024	0.005	586.901
Air Compressors	570.272	0.023	0.005	568.322
Bore/Drill Rigs	525.773	0.021	0.004	523.974
Cement and Mortar Mixers	572.278	0.023	0.005	570.320
Concrete/Industrial Saws	576.303	0.023	0.005	574.332
Cranes	529.265	0.021	0.004	527.455
Crawler Tractors	530.824	0.021	0.004	529.009
Crushing/Proc. Equipment	434.041	0.018	0.004	432.502
Dumpers/Tenders	573.970	0.023	0.005	572.007
Excavators	589.410	0.024	0.005	587.394
Forklifts	528.879	0.021	0.004	527.070
Generator Sets	570.257	0.023	0.005	568.306
Graders	533.076	0.022	0.004	531.253
Off-Highway Tractors	588.161	0.024	0.005	586.150
Off-Highway Trucks	530.825	0.021	0.004	529.010
Other Construction Equipment	529.252	0.021	0.004	527.442
Other General Industrial Equipment	589.945	0.024	0.005	587.927
Other Material Handling Equipment	530.522	0.021	0.004	528.708
Pavers	527.614	0.021	0.004	525.809
Paving Equipment	529.880	0.021	0.004	528.068
Plate Compactors	570.268	0.023	0.005	568.318
Pressure Washers	580.355	0.023	0.005	578.370
Pumps	570.247	0.023	0.005	568.297
Rollers	589.137	0.024	0.005	587.122
Rough Terrain Forklifts	530.503	0.021	0.004	528.688
Rubber Tired Dozers	534.387	0.022	0.004	532.559
Rubber Tired Loaders	528.416	0.021	0.004	526.609
Scrapers	530.519	0.021	0.004	528.705
Signal Boards	570.249	0.023	0.005	568.298
Skid Steer Loaders	530.469	0.021	0.004	528.655
Surfacing Equipment	529.064	0.021	0.004	527.255
Sweepers/Scrubbers	588.645	0.024	0.005	586.632
Tractors/Loaders/Backhoes	531.436	0.021	0.004	529.618
Trenchers	590.197	0.024	0.005	588.179
Welders	570.247	0.023	0.005	568.297

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

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2411 **Table 4-14. Greenhouse Gas Emission Factors for Off-Road Equipment – 2028**

Equipment	Emission Factor (g/hp-hr)			
	CO ₂ ^{e a}	CH ₄	N ₂ O	CO ₂
Aerial Lifts	588.917	0.024	0.005	586.903
Air Compressors	570.290	0.023	0.005	568.340
Bore/Drill Rigs	525.435	0.021	0.004	523.638
Cement and Mortar Mixers	572.290	0.023	0.005	570.333
Concrete/Industrial Saws	576.347	0.023	0.005	574.375
Cranes	529.565	0.021	0.004	527.754
Crawler Tractors	530.388	0.021	0.004	528.574
Crushing/Proc. Equipment	433.843	0.018	0.004	432.305
Dumpers/Tenders	574.192	0.023	0.005	572.228
Excavators	589.558	0.024	0.005	587.541
Forklifts	528.834	0.021	0.004	527.025
Generator Sets	570.250	0.023	0.005	568.300
Graders	533.155	0.022	0.004	531.332
Off-Highway Tractors	588.280	0.024	0.005	586.269
Off-Highway Trucks	531.114	0.021	0.004	529.297
Other Construction Equipment	528.730	0.021	0.004	526.922
Other General Industrial Equipment	589.815	0.024	0.005	587.798
Other Material Handling Equipment	530.272	0.021	0.004	528.459
Pavers	527.701	0.021	0.004	525.896
Paving Equipment	529.721	0.021	0.004	527.910
Plate Compactors	570.340	0.023	0.005	568.389
Pressure Washers	580.018	0.023	0.005	578.034
Pumps	570.294	0.023	0.005	568.344
Rollers	589.132	0.024	0.005	587.117
Rough Terrain Forklifts	530.418	0.021	0.004	528.604
Rubber Tired Dozers	534.687	0.022	0.004	532.858
Rubber Tired Loaders	528.913	0.021	0.004	527.104
Scrapers	530.423	0.021	0.004	528.609
Signal Boards	570.250	0.023	0.005	568.300
Skid Steer Loaders	530.429	0.021	0.004	528.614
Surfacing Equipment	529.125	0.021	0.004	527.315
Sweepers/Scrubbers	588.841	0.024	0.005	586.827
Tractors/Loaders/Backhoes	531.383	0.021	0.004	529.565
Trenchers	590.512	0.024	0.005	588.492
Welders	570.258	0.023	0.005	568.307

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

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- 2417 a. CO₂e calculated by summing the product of the emission factors for CO₂ and CH₄ and their respective
 2418 Global Warming Potentials (GWP). The GWP for CO₂ and CH₄ are 1 and 25, respectively.

2419 **Table 4-15. Default Horse-Powers and Load Factors for Off-Road Equipment**

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

2420
2421

2422 4.6 References

- 2423 40 CFR 89, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2424 Agency, Subchapter C-Air Programs, Part 89-Control of Emissions from New and In-Use
2425 Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency
- 2426 40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2427 Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart
2428 C-General Stationary Fuel Combustion Sources,” U.S. Environmental Protection Agency
- 2429 40 CFR 1039, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2430 Agency, Subchapter C-Air Programs, Part 1039-Control of Emissions from New and In-Use
2431 Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency
- 2432 40 CFR 1068, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2433 Agency, Subchapter C-Air Programs, Part 1068-General Compliance Provisions for Highway,
2434 Stationary, and Nonroad Programs,” U.S. Environmental Protection Agency
- 2435 SCAQMD 2007, “Software User’s Guide: URBEMIS2007 for Windows,” South Coast Air
2436 Quality Management District (SCAQMD), November 2007
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2438 2022.1,” California Air Pollution Control Officers Association (CAPCOA), April 2022
- 2439

2440 5 PORTABLE AND SEASONAL RECIPROCATING INTERNAL 2441 COMBUSTION ENGINES

2442 ➤ *Point Source*

2443

2444 5.1 Introduction

2445 Each Air Force Installation uses portable Reciprocating Internal Combustion Engine (RICE)
2446 equipment (not self-propelled) for short-term needs and seasonal activities. Portable RICE
2447 usually have wheels, skids, carrying handles, dollies, trailers, or platforms and include
2448 generators, pumps, soil tampers, air compressors, cement mixers, etc. Due to their infrequent,
2449 irregular, and non-continuous use, emissions from portable RICE are not addressed in the *Air*
2450 *Emissions Guide for Stationary Sources* but are described here.

2451

2452 Note that, a nonroad engine can become stationary if it stays at one location for more than 12
2453 consecutive months (even if it has a means of being transported, such as skids or wheels). For
2454 example, a generator with wheels providing power to a construction site office trailer is
2455 typically considered to be nonroad and portable; however, if that generator remains attached to
2456 the trailer at that construction site for longer than 12 consecutive months, it is regarded as a
2457 stationary ICE. Attempting to circumvent the rules by replacing the generator with another
2458 generator to power the construction trailer does not reset the 12-month clock. Additionally, a
2459 seasonal RICE can be considered stationary if it remains in a single location on a permanent
2460 basis (i.e., at least two years) and operates at that single location approximately three
2461 consecutive months (or more) each year. If there is uncertainty whether a portable or seasonal
2462 RICE is considered a stationary source, contact AFCEC/CZTQ for guidance.

2463

2464 In reciprocating engines, a piston moves inside a cylinder to compress an air/fuel mixture. The
2465 air/fuel mixture combusts and expands, pushing the piston through the cylinder. The piston
2466 returns, pushing out the exhaust gases, and the cycle is repeated.

2467

2468 Reciprocating engines may differ in design by the diameter of the cylinders in the engine,
2469 known as the bore, and the length of the linear movement of the piston in each cylinder, known
2470 as the stroke. The size of the engine is related to its displacement per cylinder, which is a
2471 measure of the volume of the cylinder multiplied by the length of the stroke. A reciprocating
2472 engine may be classified as either 4-stroke or 2-stroke. For a 4-stroke engine, the combustion
2473 cycle involves two revolutions of the crankshaft, to which the pistons are connected, and the
2474 cycle consists of four stages. The induction stroke occurs when the piston moves down within
2475 the cylinder, creating a vacuum and drawing in air or an air/fuel mixture. During the
2476 compression stroke, the piston moves up to pressurize the air or air/fuel mixture, which then
2477 ignites. The heated air expands generating a force on the piston such that it is forced
2478 downward again in what is called the power stroke. Finally, the piston moves upward again to

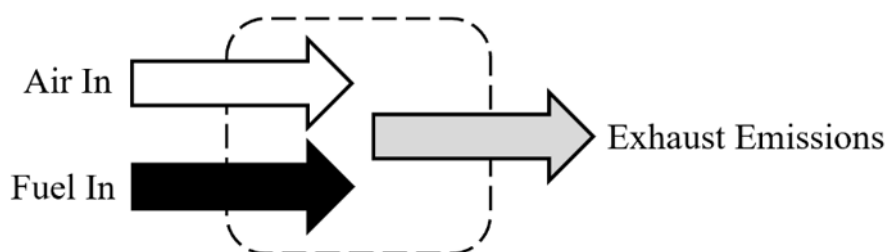
2479 force the exhaust gas out of the cylinder during the exhaust stroke and returns to the starting
2480 position of the induction stroke so the cycle may be repeated. 2-stroke engines can operate
2481 with just one revolution of the crankshaft because induction of the air or air/fuel mixture occurs
2482 concurrently with the release of the exhaust gas.

2483

2484 Detonation of the air/fuel mixture during the compression stroke may occur either through
2485 compression or spark ignition (SI). In a compression ignition (CI) engine, air is first
2486 compressed by the piston in the cylinder, which causes the temperature of the air to rise.
2487 Diesel fuel is added to the heated air and combusts since the temperature of the air is above the
2488 auto-ignition temperature of the fuel. SI engines, which use gasoline or natural gas, differ from
2489 CI engines in that the fuel/air mixture does not ignite spontaneously, but rather by a spark.

2490

2491 Emissions from portable engines will vary due to operating conditions such as temperature,
2492 humidity, torque, ignition timing, or even air/fuel mixture. An engine designed to operate near
2493 the stoichiometric air-to-fuel ratio is known as a rich-burn engine, whereas an engine that
2494 operates with excess oxygen is known as a lean-burn engine. Typically, lean-burn engines will
2495 produce fewer NO_x emissions than rich-burn engines. Variations in the air/fuel mixture for
2496 either engine type will occur due to engine wear or atmospheric conditions and even slight
2497 changes will dramatically affect pollutant emissions. Portable RICE act as point sources of
2498 emissions of criteria pollutants, HAPs, and GHGs. A simple control volume describing the
2499 emissions from portable RICE is provided in Figure 5-1.



2500

2501

Figure 5-1. Simplified Portable RICE Control Volume

2502 5.2 Emission Factors

2503 Chapter 3 of AP-42 provides EFs for RICE based on the fuel used and size of the equipment.
2504 However, increasingly stringent emissions requirements have driven the manufacture of
2505 engines to produce far less emissions than those engines that served as a basis for the
2506 development of the EFs found in AP-42. Though these EFs may apply to older engines, their
2507 use in emissions calculations for newer engines may result in the overestimation of pollutant
2508 emissions. In place of the actual EFs that are provided in AP-42, the minimum required
2509 emission standards should be used to reflect the increased efficiency and reduced emissions of
2510 the newer equipment replacing older inventory.

2511 Emissions estimates may be made utilizing the heating value and composition of the fuels used
 2512 to operate the RICE. **Typical fuel data and RICE EFs for portable use equipment are**
 2513 **provided in the “Stationary Internal Combustion” section of the *Air Emissions Guide for***
 2514 ***Air Force Stationary Sources* or the “Non-Road Engines and Equipment” section of the**
 2515 ***Air Emissions Guide for Air Force Mobile Sources.***

2516

2517 5.3 Emission Calculation

2518 There are two methods for estimating emissions from the operation of RICE – the fuel
 2519 consumption method and the load factor method. Both are described below.

2520

2521 5.3.1 Fuel Consumption Method

2522 The fuel consumption method is the simplest method for calculating the emissions from
 2523 portable and seasonal engines. All that is required is the total fuel consumed by that engine
 2524 and the EF associated with the type of engine and fuel used. The emissions are calculated as
 2525 follows:

$$2526 \quad E(\text{Pol}) = Q \times HV \times \frac{1}{10^6} \times EF(\text{Pol})$$

2527

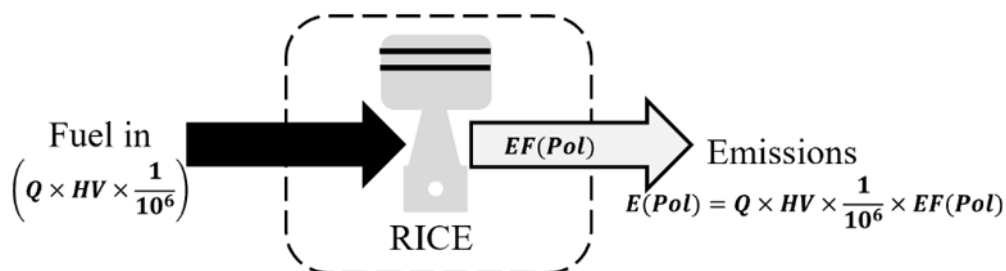
Equation 5-1

2528 Where,

2529 **E(Pol)** = Annual emissions of pollutant (lb/yr)2530 **Q** = Annual quantity of fuel consumed (gal/yr) or (ft³/yr)2531 **HV** = Heating value of the fuel used (Btu/gal) or (Btu/ft³)2532 **10⁶** = Factor to convert Btu to MMBtu (MMBtu/Btu)2533 **EF(Pol)** = Emission factor from the Stationary or Mobile Guide (lb/MMBtu)

2534

2535 A detailed representation of the emissions from portable RICE engines utilizing the fuel
 2536 consumption method is provided in Figure 5-2



2537

2538 **Figure 5-2. Portable and Seasonal Equipment Use Control Volume – Fuel Consumption**
 2539 **Method**

2540 5.3.2 Load Factor Method

2541 To calculate the most accurate emissions for portable and seasonal use engines, the first step is
 2542 to gather the required data and select the appropriate EF. **To use the load factor method, the**
 2543 **engine's rated power, operating time, and typical load factor must be known.** With the
 2544 selected EF and loading factor, the RICE emissions are calculated using the following
 2545 equation:

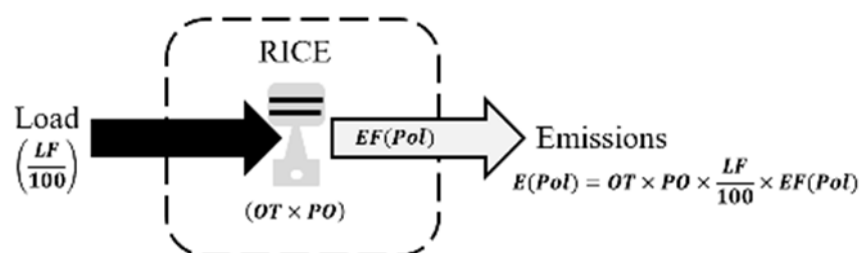
$$2546 \quad E(\text{Pol}) = OT \times PO \times \frac{LF}{100} \times EF(\text{Pol})$$

2547 **Equation 5-2**

2548 Where,

- 2549 **E(Pol)** = Annual emissions of pollutant (lb/yr)
 2550 **PO** = Rated power output of the engine (hp)
 2551 **LF** = Engine load factor (%)
 2552 **100** = Factor for converting percent to fraction (%)
 2553 **OT** = Annual engine operating time (hr/yr)

2554
 2555 A detailed representation of the emissions from portable RICE utilizing the load factor method
 2556 is provided in Figure 5-3.



2557
 2558 **Figure 5-3. Portable and Seasonal Equipment Use Control Volume - Load Factor Method**

2559 5.4 Information Resources

2560 To obtain data required for emissions calculations, contact the group responsible for
 2561 operating/maintaining the portable and seasonal equipment, typically Civil Engineering,
 2562 consult the Equipment Specification (Data or Spec) Sheets, or contact the manufacturer to
 2563 request any emissions data they may have on file for those engine models. Additionally, if the
 2564 engine's Brake Specific Fuel Consumption is available, through the spec sheet or from the
 2565 manufacturer, use that value for EF unit conversion. Finally, since SO_x emissions are a
 2566 function of the sulfur content of the fuel used, the installation's fuel supplier should be
 2567 contacted to obtain the actual average sulfur content of the fuel. These sulfur content values
 2568 should then be used in place of the averages provided in the Stationary or Mobile Guides.

2569 5.5 Example Problems

2570 5.5.1 Problem #1 – Fuel Consumption Method

2571 A USAF Base is looking to determine the NO_x emissions from an NSPS certified model year
2572 2013 diesel-fired portable generator for the previous year. Determine the NO_x emissions from
2573 this engine for last year using the fuel consumption method. This installation is not located in
2574 Alaska. The engine used a total of 12 gal of fuel last year. The engine spec sheet states that it
2575 is a 240 hp engine with a displacement of 2.1 L per cylinder.

2576
2577 **Step 1 – Select and record EF and fuel Heating Value.** The EFs for diesel-fired engines are
2578 provided in the 2021 *Air Emissions Guide for Air Force Stationary Sources*. The NO_x EF is
2579 **7.62E-01 lb/MMBtu**. The heating value of diesel is given as **138,000 Btu/gal**.

2580
2581 **Step 2 – Choose a calculation method and record the appropriate equation.** For
2582 demonstration purposes, the method was assigned in the problem statement, however, it should
2583 be noted that this is the most appropriate method to use since the power output and load factor
2584 are not provided while the annual fuel consumption is known.

2585
2586 **Step 3 – Calculate emissions.** Using the fuel quantity data and EF, NO_x emissions may be
2587 calculated using Equation 5-1.

$$2588 \quad E(Pol) = Q \times HV \times \frac{1}{10^6} \times EF(Pol)$$

$$2589 \quad E(NO_x) = 12 \frac{\text{gal}}{\text{yr}} \times 138,000 \frac{\text{Btu}}{\text{gal}} \times \frac{1}{10^6} \frac{\text{MMBtu}}{\text{Btu}} \times 0.762 \frac{\text{lb}}{\text{MMBtu}}$$

$$2590 \quad E(NO_x) = 1,656,000 \frac{\text{Btu}}{\text{yr}} \times \frac{1}{10^6} \frac{\text{MMBtu}}{\text{Btu}} \times 0.762 \frac{\text{lb}}{\text{MMBtu}}$$

$$2591 \quad E(NO_x) = 1.656 \frac{\text{MMBtu}}{\text{yr}} \times 0.762 \frac{\text{lb}}{\text{MMBtu}}$$

$$2592 \quad \boxed{E(NO_x) = 1.26 \frac{\text{lb}}{\text{yr}}}$$

2593

2594 5.5.2 Problem #2 – Load Factor Method

2595 A USAF Base must calculate emissions from a stationary diesel-fired generator. Calculate the
2596 VOCs emitted by this generator from last year using the load factor method. The installation is
2597 not located in Alaska. The generator was manufactured in 2004 and operated for 22 hours last
2598 year. The generator spec sheet shows it is 1,250 hp, the engine has a displacement of 2.0 L per
2599 cylinder, and it is not NSPS certified. The typical load factor is approximately 74%.

2600

2601 **Step 1 – Select and record EF.** EFs are provided in the 2021 *Air Emissions Guide for Air*
2602 *Force Stationary Sources*. For a 1,250 hp diesel engine manufactured in 2004 with 2.0 L per
2603 cylinder displacement, the VOC EF is **7.16E-04 lb/hp-hr**.

2604
2605 **Step 2 – Choose a calculation method and record the appropriate equation.** In this
2606 example, the emissions calculation will utilize the load factor method.

2607
2608 **Step 3 – Calculate emissions.** Using the data above, VOC emissions are calculated as
2609 follows:

$$2610 \quad E(Pol) = OT \times PO \times \frac{LF}{100} \times EF(Pol)$$

$$2611 \quad E(VOC) = 22 \frac{hr}{yr} \times 1250 \text{ hp} \times \frac{74\%}{100\%} \times 0.000716 \frac{lb}{hp-hr}$$

$$2612 \quad E(VOC) = 22 \frac{hr}{yr} \times 1250 \text{ hp} \times 0.74 \times 0.000716 \frac{lb}{hp-hr}$$

$$2613 \quad \boxed{E(VOC) = 14.57 \frac{lb}{yr}}$$

2614

2615 **5.6 References**

- 2616 40 CFR 89, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2617 Agency, Subchapter C-Air Programs, Part 89-Control of Emissions from New and In-Use
2618 Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency
- 2619 40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2620 Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart
2621 C-General Stationary Fuel Combustion Sources,” U.S. Environmental Protection Agency
- 2622 40 CFR 1039, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
2623 Agency, Subchapter C-Air Programs, Part 1039-Control of Emissions from New and In-Use
2624 Nonroad Compression-Ignition Engines,” U.S. Environmental Protection Agency
- 2625 EIA 2005, “Household Vehicles Energy Use: Latest Data & Trends,” Energy Information
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- 2630 Shires 2009, Shires, Theresa M.; Loughran, Christopher J.; Jones, Stephanie; Hopkins, Emily,
2631 “Compendium of Greenhouse Gas Emissions Estimation Methodologies for the Oil and
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2634 Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S.
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2637 Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources,
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2640 Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S.
2641 Environmental Protection Agency, November 1998
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2643 Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S.
2644 Environmental Protection Agency, July 2000
- 2645 USEPA 2004, “Regulatory Announcement: Clean Air Nonroad Diesel Rule,” U.S.
2646 Environmental Protection Agency (EPA), Office of Transportation and Air Quality, May 2004

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2648 Environmental Protection Agency (EPA), Office of Transportation and Air Quality, July 2010
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2650 Emissions Modeling," U.S. Environmental Protection Agency (EPA), Office of Transportation
2651 and Air Quality, July 2010
- 2652

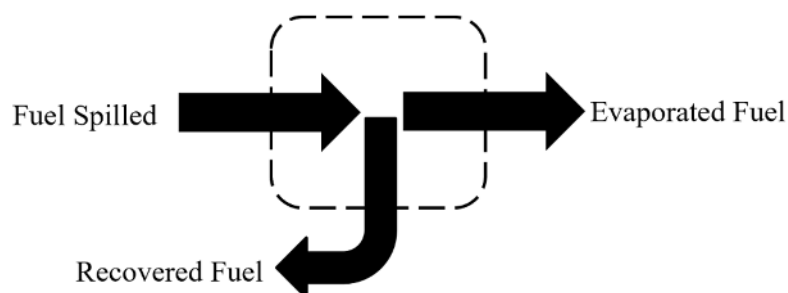
2653 6 SPILLS AND RELEASES (SPRL)

2654 ➤ *Fugitive Source*

2655

2656 6.1 Introduction

2657 Spills will inevitably occur at some point at Air Force Installations and are most often the result
 2658 of fuel transfer incidents. The most common hazardous spills involve fuels such as diesel,
 2659 gasoline, or JP-8 and, to a lesser extent, propane and Avgas. These types of spills are
 2660 significant in nature and notification of the spill to the installation Environmental Management
 2661 or the Hazardous Materials Response Team may be appropriate. Insignificant spills that result
 2662 from the filling of on-road vehicle fuel tanks are calculated using the methodology described in
 2663 the “Fuel Transfer” section of the *Air Emissions Guide for Air Force Stationary Sources*.
 2664 Whenever a spill occurs, the majority is typically recovered during cleanup, however, the
 2665 unrecovered fuel is assumed to completely evaporate into the atmosphere. **This results in the**
 2666 **emissions of VOCs and organic HAP constituents found in the fuel.** The assumption that
 2667 the unrecovered liquid completely evaporates results in conservative estimates of the emissions
 2668 from these pollutants. **Emissions from fuel spills are regarded as fugitive** and a graphic
 2669 representation of these emissions is shown in Figure 6-1.



2670

2671 **Figure 6-1. Simplified Fuel Spill Control Volume**

2672 6.2 Emissions Calculations

2673 EFs have not been developed for fuel spills. Rather, emissions from fuel spills are calculated
 2674 using a mass balance approach. The primary pollutants of concern are VOCs and organic
 2675 HAPs and calculation of emissions of these pollutants are described below.

2676

2677 6.2.1 VOC Emissions Calculations

2678 VOC emissions from spills are calculated using the following equation:

$$2679 \quad E(\text{VOC}) = (Q_S - Q_R) \times \rho = (Q_S - Q_R) \times SG \times 8.33$$

2680

Equation 6-1

2681 Where,

2682 **E(VOC)** = Annual emissions of VOCs from spills (lb/yr)

2683 **Q_S** = Annual quantity of liquid spilled (gal/yr)

2684 **Q_R** = Annual quantity of liquid recovered (gal/yr)

2685 **ρ** = Density of liquid (lb/gal)

2686 **SG** = Specific gravity of liquid

2687 **8.33** = Density of water at 70°F (lb/gal)

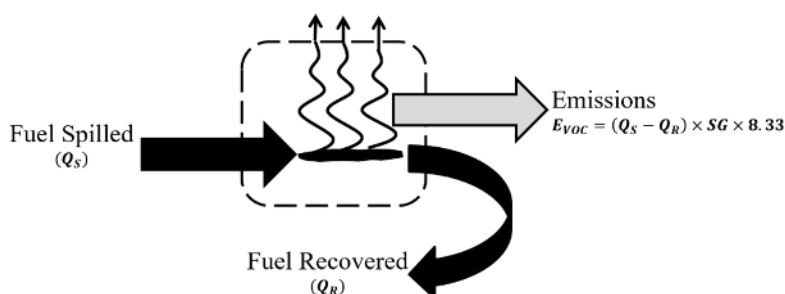
2688

2689 Note that density of a liquid is the product of the specific gravity and the density of water.

2690

2691 A more detailed control volume describing the calculation of emissions from fuel spills is

2692 given in Figure 6-2 below.



2693

2694

Figure 6-2. Fuel Spill Control Volume

2695 The fuel density will vary between fuels and from region to region. For the most accurate

2696 density values contact the fuel supplier for this information. In the absence of this data,

2697 common fuel densities are provided in Table 6-1.

2698

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

2699

2700

2701

2702

2703

2704

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.

2705 **6.2.2 HAP Emissions Calculations**

2706 When calculating emissions from fuel spills, the conservative assumption is that all
 2707 unrecovered fuel evaporates. The organic HAP emissions are calculated based on the liquid-
 2708 phase speciation of the fuel. This is accomplished using the weight fraction of the HAP as
 2709 shown in the following equation.

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

Equation 6-2

2711 Where,

2713 **E(HAP)** = Annual emissions of specific HAP (lb/yr)2714 **WP(HAP)** = Weight percent of the HAP in the liquid fuel (%)

2715

2716 As with fuel density, there is some variation in the HAP weight percent between fuels. Contact
 2717 the fuel supplier or review the SDS for guidance in determining the correct weight percent for
 2718 each HAP constituent to calculate a more accurate emission value. If this data is unavailable,
 2719 typical HAP concentrations are provided in Table 6-2.

2720 **Table 6-2. HAP Speciation of Fuels Commonly Used at Air Force Installations**

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

2721 SOURCE (unless otherwise stated): Data taken from USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection
 2722 Agency, October 2005. wt%=weight percent.

- 2723 a. Vapor pressures of pure species used in calculations were taken at 70°F and provided either by TANKS, the Hazardous
 2724 Substance Data Bank (HSDB), or were calculated using Antoine's equation constants provided either by the National
 2725 Institute of Standards and Technology (NIST) or Perry's Chemical Engineer's Handbook, 7th Ed., Perry, Robert H., 1997.
 2726 b. SOURCE: "JP-8 Composition and Variability," Armstrong Laboratory, Environics Directorate, Environmental Research
 2727 Division, May 1996. An average density of 6.71 pounds per gallon (lb/gal) was used for unit conversion.
 2728 c. The vapor phase speciation data was estimated using the liquid phase speciation data and equations found in Section 7.1.4
 2729 of AP-42, Fifth Edition, Volume I last updated November 2006.
 2730 d. SOURCE: SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February 2014. For diesel, profile 4673 was
 2731 referenced. For gasoline, profile 8748 was referenced.

2732 "----" Indicates No Data Available.
 2733

2734 **6.3 Information Resources**

2735 For information regarding fuel spills, including type of fuel, quantity spilled, and quantity
 2736 recovered, contact the base Environmental Management or CEV office. Additionally, the on-
 2737 base Fire Department, Fuels Management, or Hazardous Materials Response Team may serve
 2738 as points of contact for information regarding fuel spills.

2739

2740 **6.4 Example Problem**

2741 After contacting the CEV office, it was reported that there was a total of five significant JP-8
 2742 fuel spills on base for the previous year. It was estimated that for the five spills, a total of 625
 2743 gallons of JP-8 was spilled, of which an estimated 450 gallons were recovered. Determine the
 2744 VOC and total HAP emissions from these spills for the previous year.

2745

2746 **Step 1 – Record the density of the fuel.** The problem statement does not provide an estimate
 2747 of the density of the JP-8 spilled. After reviewing Table 6-1, it is shown that the average
 2748 density of JP-8 is **6.71 lb/gal**.

2749

2750 **Step 2 – Calculate VOC emissions.** VOC emissions are calculated using the data given in the
 2751 problem statement, the density given in Step 1, and Equation 6-1 as shown:

$$2752 \quad E(VOC) = (Q_S - Q_R) \times \rho$$

$$2753 \quad E(VOC) = \left(625 \frac{\text{gal}}{\text{yr}} - 450 \frac{\text{gal}}{\text{year}} \right) \times 6.71 \frac{\text{lb}}{\text{gal}}$$

$$2754 \quad E(VOC) = \left(175 \frac{\text{gal}}{\text{year}} \right) \times 6.71 \frac{\text{lb}}{\text{gal}}$$

$$2755 \quad \boxed{E(VOC) = 1,174.25 \frac{\text{lb}}{\text{yr}}}$$

2756

2757 **Step 3 – Select and record the wt. % of each HAP in JP-8.** Using Table 6-2, the HAP
 2758 constituents of JP-8 and their respective wt. % are: **benzene 3.36E-02, cumene 1.80E-01,**
 2759 **ethylbenzene 1.58E-01, fluorene 3.42E-03, isooctane 1.22E-03, naphthalene 2.66E-01,**
 2760 **phenylbenzene 6.74E-02, pyrene 1.24E-05, toluene 2.18E-01, and xylene 1.18E+00.**

2761

2762 **Step 4 – Calculate emissions of each HAP.** HAP emissions may be calculated using the total
 2763 VOC emissions calculated in Step 2, the weight percent of each HAP as recorded in Step 3,
 2764 and Equation 6-2.

$$2765 \quad E(HAP) = E(VOC) \times \frac{WP(HAP)}{100}$$

2786 **6.5 References**

- 2787 DLA 2006, "Petroleum Quality Information System Fuels Data (2005)," Defense Logistics
2788 Agency (DLA), Defense Energy Support Center, Technology and Standardization Division,
2789 2006
- 2790 EIA 2005, "Household Vehicles Energy Use: Latest Data & Trends," Energy Information
2791 Administration (EIA), Office of Energy Markets and End Use, U.S. Department of Energy,
2792 November 2005
- 2793 Mayfield 1996, "JP-8 Composition and Variability," Armstrong Laboratory, Environics
2794 Directorate, Environmental Research Division, May 1996
- 2795 USEPA 2005, TANKS, Version 4.09d, U.S. Environmental Protection Agency, October 2005
- 2796 USEPA 2014, SPECIATE, Version 4.4, U.S. Environmental Protection Agency, February
2797 2014
- 2798

2799 7 HOT MIX ASPHALT PLANTS (HMA)

2800 ➤ *Point* Source – From ducted sources, i.e., dryer

2801 ➤ *Fugitive* Source – From open sources, i.e., yard emissions

2802

2803 7.1 Introduction

2804 Hot Mix Asphalt (HMA) plants on Air Force Installations are typically associated with large-
2805 scale paving operations. Although uncommon, they have the potential to be a substantial
2806 contributor to emissions during the year. Emissions from HMA plants are addressed here
2807 because they are usually temporary in nature. **However, if the HMA plant is in place for**
2808 **longer than one year, it is considered a stationary source and should be added to the**
2809 **stationary source inventory.**

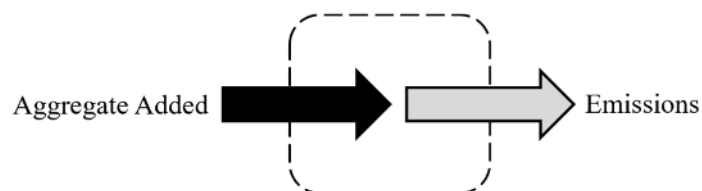
2810

2811 HMA paving materials consist of size-graded, high-quality aggregate (which often includes
2812 reclaimed asphalt pavement [RAP]) and liquid asphalt cement. The materials are mixed in
2813 precise quantities and heated to produce the HMA. The means by which the materials are
2814 mixed classify the HMA plant as either a batch or drum mix plant. In batch mix plants, the
2815 aggregate is dried before being added to a mixer with liquid asphalt cement. In a drum mix
2816 plant, the aggregate is dried and mixed with the liquid asphalt cement within the same rotary
2817 drum.

2818

2819 An HMA mixing plant may be constructed as either a permanent, a skid-mounted, or a portable
2820 plant. Although most plants have the capability to use either gaseous fuels or fuel oil, between
2821 70 and 90 percent of HMA is produced using natural gas as the preferred fuel to dry and heat
2822 the aggregate. **Emissions of concern from HMA paving operations include criteria**
2823 **pollutants, HAPs, and GHGs. The primary source of emissions includes fugitive and**
2824 **ducted emissions from dryers, hot screens, and mixers associated with production of the**
2825 **HMA.** Emissions result from both production and pre-production activities. Pre-production
2826 fugitive dust emissions include aggregate material handling, aggregate processing operations,
2827 and vehicular traffic. Emissions associated with vehicular traffic are considered mobile in
2828 nature and are addressed within the *Air Emissions Guide to Air Force Mobile Sources*.

2829 Emissions associated with on-site asphalt storage tanks may be estimated by referencing the
2830 “Storage Tanks” section of the *Air Emissions Guide for Air Force Stationary Sources*. A
2831 graphical representation of emissions from HMA plants is provided in Figure 7-1.



2832

2833

Figure 7-1. Simplified HMA Plants Emissions Control Volume

2834 **7.2 NSPS Applicability**

2835 Hot mix asphalt plants are subject to NSPS as outlined in 40 CFR 60 subpart I. This section
2836 states that no hot mix asphalt plant shall emit more than 90 mg/dscm of particulate matter or
2837 exhibit 20% or greater opacity. This section continues by outlining the requirements for
2838 proving that the facility complies with these standards. These requirements state that EPA
2839 Method 5 is used to determine PM concentration using a 60-minute run time and a sample
2840 volume of 0.90 dscm. Opacity is determined by using EPA Method 9 and procedures in 60.11.
2841

2842 **7.3 Warm Mix Asphalt (WMA) Plants**

2843 WMA is a relatively new asphalt production method. It has the benefit of utilizing lower
2844 production temperatures than HMA. Studies indicate that the ability to produce asphalt at a
2845 lower temperature result in fewer emissions. Per *Engineering Technical Letter 11-3: Warm*
2846 *Mix Asphalt (WMA)*, the Air Force allows WMA to be used for asphalt work on roads and
2847 parking lots subject to non-airfield State DOT specifications if the DOT allows WMA. At this
2848 time, there are no specific EFs published for WMA. However, there are percent reductions that
2849 represent the amount of emission produced from WMA plants relative to HMA plants.
2850

2851 **7.4 Emission Factors**

2852 In all cases, utilizing EPA Method 5 site-specific stack sampling data is the preferred method
2853 of estimating emissions from HMA operations. In the absence of such data, EFs have been
2854 developed for production related fugitive and ducted emissions. Criteria pollutant EFs are
2855 presented in Table 7-1. EFs for WMA plants were developed by applying percent reductions
2856 to HMA plant operations. These are provided in Table 7-2. At this time, no EFs have been
2857 developed for HAPs from WMA plants. Therefore, it is appropriate to use HMA HAP EFs as
2858 a surrogate. Speciated HAP EFs for HMA are provided in Table 7-3. Each state may have
2859 alternate requirements and the appropriate state or local agency should be contacted prior to
2860 calculating emissions to ensure compliance.
2861

2862 **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

2863 SOURCE: Section 11.1 – “Hot Mix Asphalt Plants,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary
2864 Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, March 2004.

- 2865 a. Control device used: fabric filter.
2866
2867 b. CO_{2e} calculated by summing the product of the emission factors for CO₂, N₂O, and CH₄ and their respective Global
2868 Warming Potentials (GWP). The emission factors were taken from AP-42 and the GWP for CO₂, N₂O, and CH₄ are 1,
2869 298, and 25, respectively.

2870

2871 **Table 7-2. Criteria Pollutant Emission Factors for Batch Mix and Drum Mix WMA
2872 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

2873 SOURCE: Colonel Lambert, A. (2011). Engineering Technical Letter (ETL) 11-3: Warm Mix Asphalt (WMA). Headquarters
2874 Air Force Civil Engineer Support Agency. Percent reductions in source document were applied to emission factors for
2875 HMA plants.

- 2876 a. There were no lead reductions applicable from source document. Therefore, HMA values are used as a surrogate.
2877
2878 b. Control device used: fabric filter.
2879 c. CO_{2e} calculated by summing the product of the emission factors for CO₂, N₂O, and CH₄ and their respective Global
2880 Warming Potentials (GWP). The emission factors were taken from AP-42 and the GWP for CO₂, N₂O, and CH₄ are 1,
2881 298, and 25, respectively.

2882

2883

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.

2884
2885
2886
2887
2888

2889 7.5 Emissions Calculations

2890 Emissions may be calculated by multiplying the appropriate EF by the activity of the HMA
2891 production rate and the hours the plant was in operation during the year, as follows:

$$2892 \quad E(\text{Pol}) = Q \times EF(\text{Pol})$$

2893 **Equation 7-1**

2894 Where,

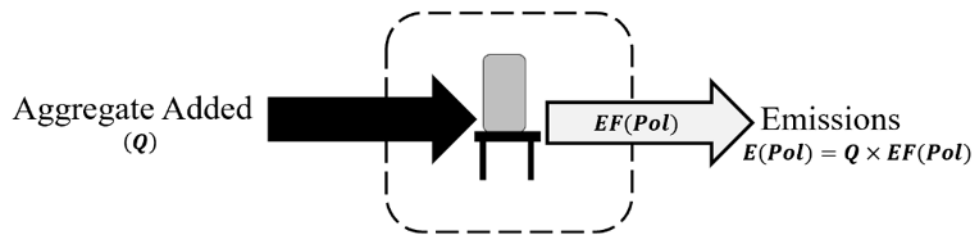
2895 **E(Pol)** = Annual emissions of pollutant (lb/yr)

2896 **Q** = Annual quantity of asphalt produced (ton/yr)

2897 **EF(Pol)** = Emission factor for a specific pollutant (lb/ton)

2898

2899 A detailed control volume depicting emissions from HMA plants is provided in Figure 7-2.



2900

2901

Figure 7-2. HMA Control Volume

2902 7.6 Information Resources

2903 HMA paving operations on base are performed by Base Civil Engineering or by a commercial
2904 contractor. Base Civil Engineering should have, or be able to obtain, the information necessary
2905 to calculate emissions from HMA plant operations.

2906

2907 **7.7 Example Problem**

2908 A USAF Base needs to calculate formaldehyde emissions from their HMA paving operations
2909 on base. Base Civil Engineering reports that the on-base HMA plant is a batch mix plant that
2910 uses natural gas for aggregate heating. The maximum production rate was 190 tons/hr and the
2911 plant was estimated to have operated for approximately 1,100 hours/yr.

2912
2913 **Step 1 – Calculate the annual quantity of asphalt produced.** The problem provided the
2914 maximum production rate and total annual operating time. The quantity may be conservatively
2915 estimated as follows:

2916
$$Q = \text{Max Production rate} \times \text{Operating Time}$$

2917
$$Q = 190 \frac{\text{ton}}{\text{hr}} \times 1,100 \frac{\text{hr}}{\text{yr}} = 209,000 \frac{\text{ton}}{\text{yr}}$$

2918
2919 **Step 2 – Select and record the appropriate EF.** Table 7-3 lists the EF of formaldehyde for
2920 batch dryers utilizing natural gas as **7.40E-04 lb/ton** of HMA produced.

2921
2922 **Step 3 – Calculate emissions.** Formaldehyde emissions associated with HMA paving
2923 operations are calculated using the recorded EF, Equation 7-1, and the information provided as
2924 follows:

2925
$$E(\text{Pol}) = Q \times EF(\text{Pol})$$

2926
$$E(\text{Formaldehyde}) = 209,000 \frac{\text{ton}}{\text{yr}} \times 0.00074 \frac{\text{lb}}{\text{ton}}$$

2927
$$E(\text{Formaldehyde}) = 154.66 \frac{\text{lb}}{\text{yr}}$$

2928

2929 **7.8 References**

- 2930 40 CFR 98 Subpart C. “Title 40-Protection of the Environment, Chapter I-Environmental
2931 Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas
2932 Reporting, Subpart C-General Stationary Fuel Combustion Sources,” U.S. Environmental
2933 Protection Agency
- 2934 Colonel Lambert, A. 2011. Engineering Technical Letter (ETL) 11-3: Warm Mix Asphalt
2935 (WMA). Headquarters Air Force Civil Engineer Support Agency. August 2011
- 2936 USEPA 2000, “Hot Mix Asphalt Plants: Emission Assessment Report (EPA-454/R-00-019),”
2937 U.S. Environmental Protection Agency, Office of Air Quality, Planning and Standards,
2938 December 2000
- 2939 USEPA 2004, Section 11.1-“Hot Mix Asphalt Plants,” Compilation of Air Pollutant Emission
2940 Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental
2941 Protection Agency, March 2004.
- 2942
- 2943

2944
2945

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2946 8 CONCRETE BATCH PLANT (CB)

2947 ➤ *Point Source* – From ducted sources, i.e., dryer

2948 ➤ *Fugitive Source* – From open sources, i.e., yard emissions

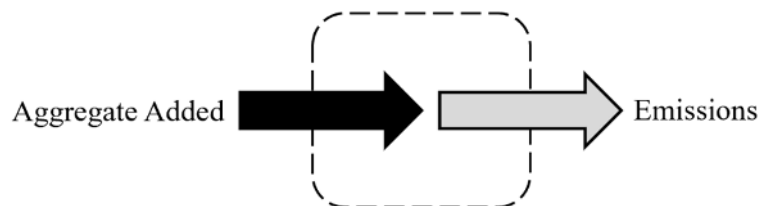
2949

2950 8.1 Introduction

2951 Concrete batch (CB) plants at Air Force Installations are typically associated with large-scale
2952 construction operations. Concrete is mostly composed of water, cement, sand (fine aggregate),
2953 and coarse aggregate. Although uncommon, they have the potential to be a substantial
2954 contributor to emissions during the year. Emissions from concrete batch plants are addressed
2955 here because they usually accompany activities relating to construction or repair. However, if
2956 a concrete plant is in place for longer than one year, it must be considered a stationary source
2957 and added to the stationary source inventory.

2958

2959 There are two types of concrete batch plants: truck mix and central mix plants. Truck mix are
2960 also referred to as dry mix plants. The dry ingredients, such as sand, gravel, and cement, are
2961 mixed in a chute and subsequently deposited into a mixer truck. Water is discharged through
2962 the chute and into the mixer truck, and the material is agitated during transportation to the job
2963 site. Central mix plants are also referred to as wet mix plants. Central mix plants have a
2964 central mixing device in which all ingredients, including the water, are blended and then
2965 deposited into a vehicle for transportation to the job site. A simple control volume is shown in
2966 Figure 8-1.



2967

2968 **Figure 8-1. Simplified Concrete Batch Plant Emissions Control Volume**

2969 8.2 Emission Factors

2970 EFs have been developed for material handling processes associated with CB plants.
2971 Algorithms and EFs used by the Air Force are generally from AP-42. Concrete batch plant
2972 metallic HAP EFs are presented in Table 8-1. Plant-wide particulate EFs associated central
2973 and truck mix concrete are provided in Table 8-2

2974

2975

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

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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.

2985

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

2986

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2993

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

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

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

2994 8.3 Emissions Calculations

2995 Emissions may be calculated by multiplying the appropriate EF by the emission rate of the
 2996 pollutant-emitting activity and the hours the plant was in operation during the year, as follows:

$$2997 \quad E(\text{Pol}) = Q \times EF(\text{Pol})$$

2998 **Equation 8-1**

2999

3000 Where,

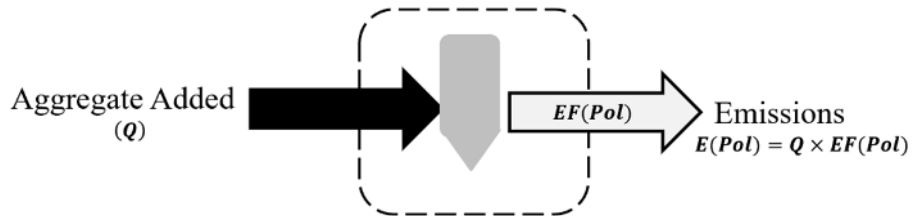
3001 **E(Pol)** = Annual emissions of pollutant (ton/yr)

3002 **Q** = Annual quantity of asphalt produced (ton/yr)

3003 **EF(Pol)** = Emission factor for a specific pollutant (lb/ton)

3004

3005 A detailed control volume depicting the emissions from concrete batch plants is given in Figure
 3006 8-2.



3007

3008

Figure 8-2. Concrete Batch Plant Control Volume

3009 8.4 Information Resources

3010 CB plant operations on an installation are performed by base Civil Engineering or by a
 3011 commercial contractor. Base Civil Engineering should have, or be able to obtain, the
 3012 information necessary to calculate emissions from CB plant operations.

3013

3014 8.5 Example Problems

3015 8.5.1 Problem #1

3016 A USAF Base needs to calculate total chromium emissions from their central mix batching
 3017 operations on base. Base Civil Engineering reports that the on-base CB plant is a controlled
 3018 central mix plant. The maximum production rate was 210 tons/hr and the plant was estimated
 3019 to have operated for approximately 900 hours/yr.

3020

3021 **Step 1 – Calculate the annual quantity of concrete produced.** The problem provided the
 3022 maximum production rate and total annual operating time. The quantity may be conservatively
 3023 estimated as follows:

3024 $Q = \text{Max Production Rate} \times \text{Operating Time}$

3025 $Q = 210 \frac{\text{ton}}{\text{hr}} \times 900 \frac{\text{hr}}{\text{yr}} = 189,000 \frac{\text{ton}}{\text{yr}}$

3026

3027 **Step 2 – Select and record the appropriate EF.** Table 8-1 lists the EF of total chromium for
3028 controlled central mix batching as **1.27E-07 lb/ton** of concrete.

3029

3030 **Step 3 – Calculate emissions.** Total chromium emissions associated with central mix batching
3031 operations are calculated using the recorded EF, Equation 8-1, and the information provided as
3032 follows:

3033 $E(\text{Pol}) = Q \times EF(\text{Pol})$

3034 $E(\text{Chromium}) = 0.000000127 \frac{\text{lb}}{\text{ton}} \times 189,000 \frac{\text{ton}}{\text{yr}}$

3035 $E(\text{Chromium}) = 0.024 \frac{\text{lb}}{\text{yr}}$

3036

3037 8.5.2 Problem #2

3038 A USAF Base needs to calculate PM_{2.5} emissions from their CB plant operations that include
3039 weigh hopper loading and central mix loading. Base Civil Engineering reports that the on-base
3040 CB plant is a controlled central mix plant. The maximum production rate was 210 tons/hr and
3041 the plant was estimated to have operated for approximately 900 hr/yr. According to Chapter 11
3042 of AP-42, for conversion purposes, there are 4,024 pounds of material in one cubic yard of
3043 concrete.

3044

3045 **Step 1 – Calculate the annual quantity of concrete produced.** The problem provided the
3046 maximum production rate and total annual operating time. The quantity may be conservatively
3047 estimated as follows:

3048 $Q = \text{Max Production Rate} \times \text{Operating Time}$

3049 $Q = 210 \frac{\text{ton}}{\text{hr}} \times 900 \frac{\text{hr}}{\text{yr}} = 189,000 \frac{\text{ton}}{\text{yr}}$

3050

3051 **Step 2 – Select and record the appropriate EFs.** Table 8-2 lists the EFs for PM_{2.5} as **0.0026**
3052 **lb/yd³** for weigh hopper loading and **0.0010 lb/yd³** for central mix loading.

3053

3054 **Step 3 – Calculate emissions.** PM_{2.5} emissions associated with weigh hopper loading and
3055 central mix loading are calculated using the recorded EFs, Equation 8-1, and the information
3056 provided as follows:

3057 $E(Pol) = Q \times EF(Pol)$

3058 $E(PM_{2.5})_{weigh\ hopper\ loading} = 0.0026 \frac{lb}{yd^3} \times \frac{1\ yd^3}{4024\ lb} \times 189,000 \frac{ton}{yr} \times \frac{2000\ lb}{ton} =$

3059 $244.23 \frac{lb}{yr}$

3060 $E(PM_{2.5})_{central\ mix\ loading} = 0.0010 \frac{lb}{yd^3} \times \frac{1\ yd^3}{4024\ lb} \times 189,000 \frac{ton}{yr} \times \frac{2000\ lb}{ton} = 93.94 \frac{lb}{yr}$

3061

3062 **Step 4 – Sum total PM emissions.** Add the PM_{2.5} emissions from both the weight hopper and
3063 central mix loading for the total PM_{2.5} emissions.

3064 $E(PM_{2.5}) = (244.23 + 93.94) \frac{lb}{yr}$

3065 $E(PM_{2.5}) = 338.17 \frac{lb}{yr}$

3066

3067

3068 8.6 References

3069 Section 11.12 – “Concrete Batching,” Compilation of Air Pollutant Emission Factors – Volume
3070 I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency,
3071 June 2006

3072 9 SITE REMEDIATION (RDL)

3073 ➤ *Point* Source – Remediation System

3074 ➤ *Fugitive* Source – Emissions from Contamination Site

3075

3076 ***Site Remediation can potentially be a stationary source if collocated at a major source of**
3077 **HAPs and subject to 40 CFR 63 Subpart GGGGG, which currently (June 2023) applies**
3078 **to less than five USAF installations. Refer to *Air Emissions Guide for USAF Stationary***
3079 ***Sources* for additional information.**

3080

3081 9.1 Introduction

3082 Air Force Installations occasionally have sites that are contaminated with hazardous substances
3083 because of chemical leaks, spills or prior disposal practices that require site remediation. The
3084 Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and the
3085 Resource Conservation and Recovery Act (RCRA) require the remediation of sites
3086 contaminated by hazardous materials that pose a risk to public health or the environment.
3087 Additional guidelines and procedures for remediation of these sites are further defined under
3088 the National Contingency Plan (NCP).

3089

3090 During CERCLA response actions/RCRA corrective actions, Environmental Restoration
3091 Program Managers (ERPMS) must remain cognizant of, and comply with, certain requirements
3092 that are promulgated under the authority of other statutes (e.g., Clean Air Act or the Toxic
3093 Substances Control Act). Program specific requirements may have a dramatic impact on which
3094 remedies may be feasible because of the regulatory and/or technical constraints imposed under
3095 other environmental regulatory programs.

3096

3097 CERCLA response actions that are conducted entirely on-site do not require Federal, State, or
3098 local permits, but must comply with substantive requirements that are either “applicable” or
3099 “relevant and appropriate.” Wastes collected using actions of CERCLA that are transferred
3100 off-site must comply with the CERCLA Off-site Rule as well as the substantive and
3101 administrative requirements. Off-site actions, however, are not governed by the concept of
3102 relevance and appropriateness.

3103

3104 During RCRA corrective actions, ERPMS must comply with both substantive and
3105 administrative requirements that are applicable to a specific corrective action including the
3106 administrative requirement of applying for, obtaining, and operating under an approved permit.
3107 These actions, however, need not comply with requirements that are deemed only relevant and
3108 appropriate.

3109

3110

3111 **9.2 Air Quality Regulatory Requirements**

3112 The EPA has promulgated regulations and policies to provide practical approaches which allow
3113 flexibility in managing site remediation. Often, regulations applicable to site remediation
3114 involve treating, storing, disposing, or re-disposing hazardous waste. Generally, the regulatory
3115 approach requires that on-site remedial actions must attain or exceed (or waive in some
3116 circumstances) Federal and State Applicable or Relevant and Appropriate Requirements
3117 (ARARs) of environmental regulations and policies.

3118

3119 **9.2.1 Applicable or Relevant and Appropriate Requirements (ARARs)**

3120 When attempting to determine whether specific CAA requirements are potential ARARs and,
3121 more specifically, whether they are either “applicable” or “relevant or appropriate” to
3122 remediation activities, ERPMs may need to know the following:

- 3123 • Air quality designation of the site’s location (i.e., attainment, nonattainment,
3124 unclassified, transport) for each NAAQS,
- 3125 • Classification of each designated nonattainment area (e.g., marginal, moderate, or
3126 serious),
- 3127 • Whether construction or modification of their stationary source commenced after the
3128 date of publication of regulations (or proposed regulations) prescribing a standard of
3129 performance that governs such source,
- 3130 • Required control measures including emissions limitations and emissions offsets, and
- 3131 • Baseline emission estimates at the site and estimated (i.e., modeled) air pollutant
3132 emissions associated with the site investigation activities, construction of remedy, and
3133 subsequent operation and maintenance of the remedy. (EPA, 1992a)

3134

3135 **9.2.2 ARAR Waivers**

3136 Waivers, which by statute apply to on-site CERCLA remedial actions, must be invoked for
3137 each ARAR that will not be attained. Because removal actions must comply with ARARs to
3138 the extent practicable, waivers are also available for removal actions. Six statutory waivers are
3139 codified under 40 CFR 300.430(f)(1)(ii)(C)(1)-(6) and include the following (see also 55
3140 FR8747-50):

- 3141 • Interim measures,
- 3142 • Greater risk to health and the environment,
- 3143 • Technical impracticability from an engineering perspective,
- 3144 • Equivalent standard of performance,

- 3145 • Inconsistent application of State standards, and
- 3146 • Fund balancing.

3147
3148 In addition to statutory waivers, ERPMS may consider the existence of exclusions, exemptions,
3149 and variances under other laws because often environmental or technical reasons exist for such
3150 provisions. However, even if an exclusion, exemption, or variance provision matches the
3151 circumstances at the site, ERPMS should be aware that a requirement may remain relevant and
3152 appropriate for other reasons.

3153
3154 Sufficient information, available at the time of Record of Decision (ROD) signature, may
3155 indicate the possibility that an ARAR waiver may be invoked at a site (e.g., the remedial
3156 investigation/feasibility study (RI/FS) indicates it may be technically impracticable to attain
3157 Maximum Contaminant Levels (MCLs) in ground water). ERPMS should then consider
3158 including contingency language in the ROD.

3159

3160 **9.2.3 Major Source of Hazardous Air Pollutants (HAPs)**

3161 Under the 1990 amendments to the CAA, stationary sources of HAPs regulated under 40 CFR
3162 Part 61 and categories of sources regulated under 40 CFR Part 63 resulting from CERCLA
3163 response activities at a facility may be subject to CAA authority. CAA §112(b)(1) contains a
3164 complete list of the 189 HAPs, which include compounds (i.e., any unique substance that
3165 contains the named chemical such as cobalt, cyanide, or mercury as part of that chemical's
3166 infrastructure) and radionuclides.

3167
3168 Major sources of HAPs are stationary sources, or a group of stationary sources located within a
3169 contiguous area and under Department of Defense (DoD) control that emit or have the potential
3170 to emit, in the aggregate, 10 tons or more per year of a single HAP or 25 tons or more per year
3171 of any combination of HAPs, after emission controls are considered. ERPMS may be required
3172 to apply the EPA-developed MACT standards at CERCLA sites with a source category that
3173 emits or has the potential to emit HAPs. This is dependent on whether the source qualifies as a
3174 major source. For an area source (i.e., any stationary source of HAPs that is not a major
3175 source), ERPMS may be able to use Generally Available Control Technology (GACT) or
3176 management practices as a substitute for MACT standards.

3177
3178 In 1989, EPA issued a Statement of Policy to guide decision makers on (1) the use of controls
3179 for air emissions from air strippers and other vented sources of VOCs used at CERCLA
3180 response sites for ground water treatment and (2) the establishment of procedures for
3181 implementation. ERPMS responsible for sites that are implementing pump-and-treat operations
3182 may identify air stripping, during which VOCs in the water are transferred to a vapor phase as
3183 an integral component of the remedial alternative. One known side effect of air stripping is the

3184 emission of VOCs into the ambient air. At a minimum, the five major types of information
3185 that should be generated during the RI/FS are:

- 3186 • Emission data, including the pollutants expected to be emitted and the rate of emission
3187 for each pollutant (e.g., TCE emissions rate from all air strippers at the site),
- 3188 • Consideration of health risks from the execution of the remedy as well as from the
3189 uncontrolled site,
- 3190 • Control alternatives and their costs,
- 3191 • Ozone attainment status, and
- 3192 • Potential air ARARs.

3193

3194 Major stationary sources defined under 40 CFR 70.2 (e.g., sources that emit or have the
3195 potential to emit 10 tons/year or more of VOCs in areas classified as severe) are also
3196 considered major sources for the criteria pollutant (e.g., ozone). New major stationary sources
3197 or major modifications located in any area that cause, or contribute to, a violation of any of the
3198 six NAAQS must meet certain criteria (e.g., specific emission standards, LAERs). RCRA
3199 corrective action units releasing these pollutants may require approved construction permits
3200 (before construction, installation, or modification of the unit) and operating permits, which
3201 identify emission rates and limitations, process rates, and maximum operation conditions.
3202 Under §121(e) of CERCLA, CERCLA response actions that are conducted entirely on-site will
3203 not require permits for actions carried out in compliance with §121 but may require approved
3204 emission rates and limitations, process rates, and maximum operation conditions.

3205

3206 **9.2.4 National Ambient Air Quality Standards**

3207 NAAQS are standards established by the EPA under authority of the CAA that apply to
3208 outdoor air throughout the country. NAAQS are not enforceable in and of themselves and are
3209 never ARARs. They may, however, constitute To-Be-Considered (TBC) materials under
3210 CERCLA actions. It is the emission standards, which are promulgated by the state to attain the
3211 NAAQS, that are directly enforceable and are potential ARARs. NAAQS do not apply during
3212 RCRA corrective actions, unless legally applicable.

3213

3214 **9.2.5 New Source Performance Standards (NSPS)**

3215 Under the NSPS program, EPA established nationally uniform standards for major new
3216 stationary sources, particularly for industrial source categories. These categories are listed in
3217 40 CFR 60. NSPS are based on Best Demonstrated Technology (BDT), which EPA may
3218 define as an emission limit or rate (i.e., a specified number of pounds per hour) or a
3219 technological system of continuous emission reduction. At present, the NSPS source
3220 categories coincide with only a few of the air pollutant emission sources typically found at

3221 CERCLA sites. Thus, NSPS are not typically considered “applicable” to CERCLA activities.
3222 They may be “relevant and appropriate” if the pollutant emitted and the technology employed
3223 during remediation are sufficiently similar to the pollutant and source category regulated by
3224 NSPS. This is a site-specific determination.
3225

3226 **9.2.6 RCRA Subparts AA, BB, and CC**

3227 Air emission standards under RCRA (Subparts AA, BB, and CC of 40 CFR Parts 264 and 265)
3228 may be applicable to CERCLA response actions/RCRA corrective actions. Air emission
3229 standards of Subpart AA concern process vents associated with specific operations (i.e., air or
3230 steam stripping, solvent extraction, thin-film evaporation, fractionation, or distillation).
3231 Standards of Subpart BB concern equipment (e.g., pumps, valves, pressure relief devices).
3232 These standards will be “applicable” during ground water treatment provided:

- 3233 • For subpart AA, the contaminated water managed in a specified operation has an annual
3234 average total organic concentration of 10 ppmw or greater (DOE 1993a), or
- 3235 • For Subpart BB, the equipment contains or contacts hazardous wastes with organic
3236 concentrations of at least 10 percent by weight (DOE 1993b), and
- 3237 • The contaminated ground water qualifies as hazardous waste, and
- 3238 • The contaminated ground water is being managed at a RCRA Treatment, Storage, and
3239 Disposal Facility (TSDF) or 90-day generator.

3240
3241 Although not pertinent to RCRA corrective actions, Subparts AA and BB control requirements
3242 may considered “relevant and appropriate” to on-site CERCLA actions that use one of the
3243 previously discussed technologies when managing wastes that are not otherwise subject to
3244 Subparts AA or BB (e.g., wastes with organic concentration of less than 10 ppmw/10 percent
3245 by weight, organics from nonhazardous waste) (55FR 25458) (EPA 1992).

3246
3247 Subpart CC standards govern the management of organics in containers, tanks, surface
3248 impoundments, and miscellaneous units (when appropriate). These standards apply to TSDFs
3249 and 90-day generators accumulating waste on-site in permit-exempt tanks and containers.
3250

3251 **9.3 Remediation Technologies**

3252 Typically, contaminants on Air Force Installations consist of either organic solvents (e.g.,
3253 perchloroethylene, trichloroethylene) or petroleum products (e.g., jet or diesel fuels, etc.).
3254 Identification, investigation, and cleanup of these contaminants on active Air Force and Base
3255 Realignment and Closure (BRAC) installations falls under the jurisdiction of the DoD’s
3256 Environmental Restoration Program (ERP). The Air Force Civil Engineer Center (AFCEC)

3257 also provides additional support for restoration programs through its Environmental
3258 Restoration Division (CZR).
3259 There are a variety of technologies available to remediate contaminants from soil and
3260 groundwater. The contaminant(s) targeted for removal dictate the specific technology selected
3261 for the remediation process, though two or more remediation methods are often used in
3262 conjunction. Some of these technologies involve the transfer of the existing contaminant from
3263 the vadose (i.e., unsaturated) and/or phreatic (i.e., saturated) soil zones into an air stream,
3264 which may either be vented directly into the atmosphere or through a control device (e.g.,
3265 biofiltrator, carbon adsorber, catalytic or thermal oxidizer, etc.). Air emissions from the use of
3266 these technologies must then be calculated for air emission inventory purposes. Site
3267 remediation is performed only on a temporary basis and only in response to the clean-up of
3268 sites where hazardous material was released.

3269
3270 Emissions of concern from site remediation projects are VOCs from organic contaminants,
3271 other criteria pollutants, HAPs, and GHGs, depending upon the contaminant in question. The
3272 contaminant involved at each remediation site (including any intermediate or final degradation
3273 products of the initial contaminant) must be known to calculate emissions. Emissions are
3274 calculated following a simple mass balance approach, as any contaminant not captured by
3275 control devices or still incorporated in the soil or groundwater at the remediation site is
3276 assumed to have vented directly into the atmosphere. Air emissions at sites that are being
3277 remediated are both point and fugitive. **The pollutants emitted from the contamination site**
3278 **are fugitive while those released into the atmosphere by the remediation equipment are**
3279 **point sources.**

3280

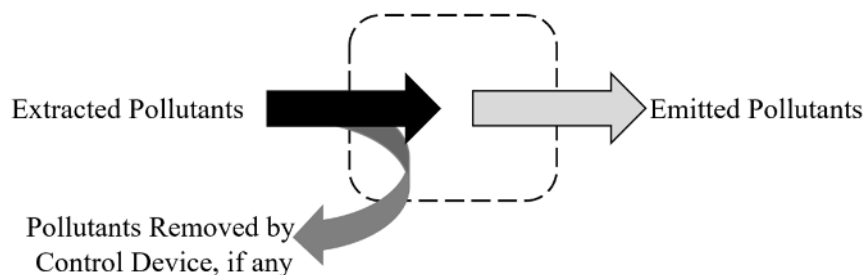
3281 9.4 Emission Sources

3282 The Site Remediation NESHAP lists three groups of affected sources: Process Vents,
3283 Remediation Material Management Units, and Equipment Leaks. The three groups are
3284 described in the following sections:

3285

3286 9.4.1 Process Vents

3287 Process Vents include the entire group of process vents associated with the in-situ and ex-situ
3288 remediation process to remove, destroy, degrade, transform, or immobilize hazardous
3289 substances in remediation material. The two most common technologies used in site
3290 remediation that result in air emissions through process vents are Soil Vapor Extraction (SVE)
3291 and Air Stripping (AS). In some cases, any air emissions resulting from site remediation
3292 technologies may be considered negligible and may not need to be quantified. Before making
3293 that determination, the appropriate local/state regulatory board should be contacted. A simple
3294 control volume detailing the emissions from site remediation is provided in Figure 9-1.



3295

3296

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

3297 The calculation of emissions from site remediation requires testing and monitoring to
3298 determine pollutant concentration, which, as described in the following sections, may be used
3299 in conjunction with the flow rate to determine air emissions. For this reason, there are no
3300 emission factors that have been developed that are applicable to the direct emissions of
3301 pollutants at remediation sites. However, site remediation often involves a control device, such
3302 as a flare, to combust exhaust gas. Whenever a combustion source is used, the emissions
3303 generated must also be addressed. The method for calculation is not addressed here, but in the
3304 “External Combustion” section of the *Air Emissions Guide for Air Force Stationary Sources*.

3305

3306 Emissions from SVE and AS remediation technologies are calculated in a similar, though
3307 slightly different manner. Emissions from these are a function of the airflow or water pumping
3308 rate, the concentration of the pollutant, and the control efficiency of the control device if
3309 present. Air emissions calculations from SVE and AS are described below.

3310

3311 **9.4.1.1 Soil Vapor Extraction (SVE)**

3312 SVE is a remediation technology used to remove pollutants from soil within the vadose zone.
3313 One or more extraction wells are placed near the contaminant plume. These wells introduce a
3314 pressure gradient, resulting in air flow towards an extraction well. Any existing pollutants are
3315 transferred into the passing air stream and the resulting contaminant-laden air stream is then
3316 either vented directly into the atmosphere or to a control device. The concentration of the
3317 pollutant is measured by a Flame Ionization Detector (FID) or Photo Ionization Detector (PID)
3318 device from that point source. A FID works by detecting the ions created by the combustion of
3319 gas, which flows through a flame. This device is sensitive to hydrocarbons though the
3320 presence of atoms besides hydrogen and carbon reduce the detector’s response. A PID
3321 contains an ultraviolet (UV) lamp that ionizes the incoming gas. The ions are driven to a
3322 collector electrode that measures the resultant current, which directly correlates to the
3323 concentration of the analyte in the sample. Note that it may be necessary to apply a correction
3324 (or scaling) factor to the reading provided by the PID. The correction factor is a measure of the
3325 sensitivity of the photoionization detector to a specific gas. Some PIDs may provide the value
3326 of the target chemical after it has been corrected with the scaling factor, but this may need to be
3327 performed manually for an accurate measure of the chemical concentration.

3328 Air emissions from SVE are calculated per extraction well. In general, technologies resulting
 3329 in air emissions will have a point source of the pollutant that is either directly discharged into
 3330 the atmosphere or through a control device. It is preferable to sample SVE systems at the point
 3331 where pollutants are released from the process vent into the atmosphere. Alternatively, the
 3332 system may be sampled prior to the air stream entering a control device.

3333

3334 Emissions from each extraction well should be calculated individually and summed for the
 3335 total emissions per chemical species. The pollutant emissions from SVE systems may be
 3336 calculated as follows:

$$3337 \quad E(\text{Pol}) = Q \times C(\text{Pol}) \times MW(\text{Pol}) \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

3338 **Equation 9-1**

3339 Where,

3340	E(Pol)	= Emissions of a pollutant (lb/yr)
3341	Q	= Flow rate of the extracted air (ft ³ /min)
3342	C(Pol)	= Concentration of the pollutant in the extracted air (ppmv)
3343	MW(Pol)	= Molecular weight of the pollutant (lb/lb-mole)
3344	1.581x10⁻⁷	= Equation constant [(lb-mole min)/(ppmv ft ³ hr)]
3345	t	= Time in operation during the year (hr/yr)
3346	CE	= Control efficiency of the control device, if present (%)
3347	100	= Factor converting percent to a fraction (%)

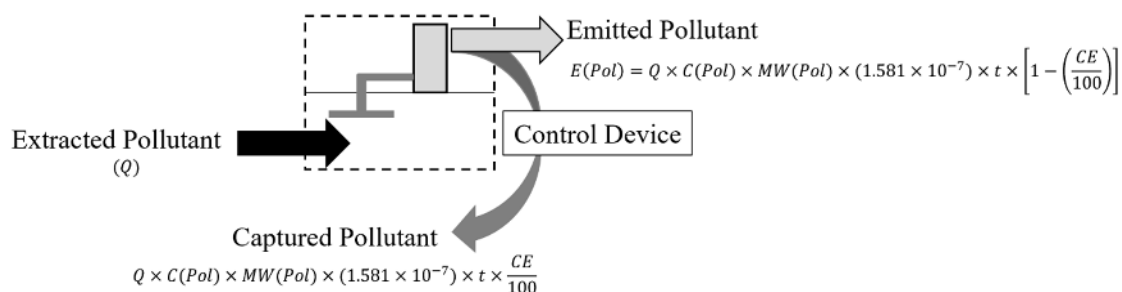
3348

3349 The equation constant was derived as follows:

$$3350 \quad \frac{1}{10^6 \text{ ppmv}} \times \frac{60 \text{ min}}{1 \text{ hr}} \times \frac{1 \text{ lb-mole}}{379.5 \text{ ft}^3} = 1.581 \times 10^{-7} \frac{\text{lb-mole} \cdot \text{min}}{\text{ppmv} \cdot \text{ft}^3 \cdot \text{hr}}$$

3351

3352 A detailed control volume of emissions from soil vapor extraction is provided in Figure 9-2.



3353

3354 **Figure 9-2. Soil Vapor Extraction Control Volume**

3355 **9.4.1.2 Air Stripping (AS)**

3356 Air stripping is often utilized concurrently with SVE methods of remediation for contaminated
 3357 ground or surface water. Once the contaminated water is pumped to the treatment site, it is
 3358 introduced into an air stripping or aeration tank, which is filled with a packing material that
 3359 impedes the flow of the water. While the water is pumped downwards, air is injected from the
 3360 bottom of the tank and flows counter to the flow of the water pumped into the tank. The
 3361 packing material increases the exposure time between the air and water. The target
 3362 contaminant is volatilized into the air stream, which flows out the top of the tank. The air
 3363 stream may either be vented directly into the atmosphere or to a control device.

3364
 3365 As with SVE systems, the preferred sampling point is where pollutants are released from the
 3366 process vent into the atmosphere. An alternate sampling point would be prior to the aeration
 3367 tank. If the air stripping system is sampled at the preferred location, Equation 9-1 is used to
 3368 calculate pollutant emissions from the system.

3369
 3370 To calculate emissions from air strippers based on groundwater input at the alternate sampling
 3371 point, the pollutant concentration in the groundwater must first be measured. Air emissions
 3372 resulting from air strippers are calculated as follows:

$$3373 \quad E(\text{Pol}) = Q \times C(\text{Pol}) \times \frac{RE}{100} \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

3374 **Equation 9-2**

3375 Where,

- 3376 **Q** = Groundwater pumping rate (gal/min)
 3377 **C(Pol)** = Concentration of the pollutant in the groundwater (mg/L)
 3378 **RE** = Removal efficiency of the air stripper (%)
 3379 **100** = Factor converting percent to a fraction (%)
 3380 **5.042x10⁻⁴** = Equation constant [(lb L min)/(mg gal hr)]

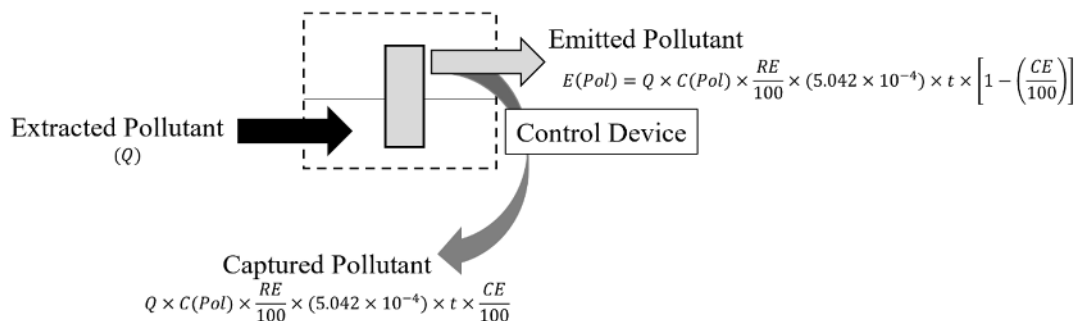
3381

3382 The equation constant was derived as follows:

$$3383 \quad \frac{lb}{10^6 mg} \times \frac{60 min}{1 hr} \times \frac{1000 L}{261.8 gal} = 5.042 \times 10^{-4} \frac{lb \cdot L \cdot min}{mg \cdot gal \cdot hr}$$

3384

3385 A detailed control volume of emissions from air stripping is provided in Figure 9-3



3386

3387

Figure 9-3. Air Stripping Control Volume

3388 9.4.2 Remediation Material Management Units

3389 Remediation material management units are devices used to hold and manage remediation
 3390 materials. A tank or container equipped with a vent that serves as a process vent is not a
 3391 remediation material management unit. These devices include but are not limited to tanks,
 3392 surface impoundments, oil-water separators, and organic-water separators. Methods for
 3393 calculating pollutant emissions from remediation material management units can be found in
 3394 the “Storage Tanks” section of the *Air Emissions Guide for Air Force Stationary Sources*.
 3395

3396 9.4.3 Equipment Leaks

3397 Equipment leaks are leaks from the entire group of equipment components associated with a
 3398 remediation site. These include but are not limited to pumps, valves, and pipe connections.
 3399 Methods for calculating pollutant emissions from equipment leaks can be found in the “Spills
 3400 and Releases” section of this Guide.
 3401

3401

3402 9.5 Information Resources

3403 All site restoration activities on active Air Force Installations are overseen by Base
 3404 Environmental (CEV), which may be contacted for any information required to calculate air
 3405 emissions. Additionally, the contractor operating the remediation system(s) may also be
 3406 contacted to obtain any required information.
 3407

3407

3408 9.6 Example Problems

3409 9.6.1 Problem #1 (Soil Vapor Extraction)

3410 A USAF Base is looking to calculate air emissions from a remediation site located on base.
 3411 SVE was used to remove perchloroethylene (PCE) from one extraction well at this location.
 3412 The SVE process was in operation for approximately 1200 hours with an air flow rate of 120
 3413 ft³/min and an average measured PCE concentration of 215 ppmv. The extracted air was
 3414 vented to a catalytic oxidizer, with a stated control efficiency of 97%, prior to being released to

3415 the atmosphere. Given that the molecular weight of PCE is 165.8 lb/lb-mole, calculate the
3416 emissions of PCE from this process at this site.

3417

3418 **Step 1 – Calculate emissions.** All the data required for emissions calculation is provided in
3419 the problem statement. Using this data and Equation 9-1, emissions may be calculated as
3420 follows:

$$3421 \quad E(Pol) = Q \times C(Pol) \times MW(Pol) \times (1.581 \times 10^{-7}) \times t \times \left[1 - \left(\frac{CE}{100} \right) \right]$$

$$3422 \quad E(PCE) = 120 \frac{ft^3}{min} \times 215 \text{ ppmv} \times 165.8 \frac{lb}{lb-mole} \times (1.581 \times 10^{-7}) \frac{lb-mole \text{ min}}{ft^3 \text{ ppmv hr}} \times$$

$$3423 \quad 1200 \frac{hr}{yr} \times \left[1 - \left(\frac{97\%}{100\%} \right) \right]$$

$$3424 \quad E(PCE) = 120 \frac{ft^3}{min} \times 215 \text{ ppmv} \times 165.8 \frac{lb}{lb-mole} \times (1.581 \times 10^{-7}) \frac{lb-mole \text{ min}}{ft^3 \text{ ppmv hr}} \times$$

$$3425 \quad 1200 \frac{hr}{yr} \times [1 - 0.97]$$

$$3426 \quad E(PCE) = 120 \frac{ft^3}{min} \times 215 \text{ ppmv} \times 165.8 \frac{lb}{lb-mole} \times (1.581 \times 10^{-7}) \frac{lb-mole \text{ min}}{ft^3 \text{ ppmv hr}} \times$$

$$3427 \quad 1200 \frac{hr}{yr} \times [0.03]$$

$$3428 \quad E(PCE) = 4,277,64 \frac{ft^3 \text{ ppmv lb}}{min \text{ lb-mole}} \times (1.581 \times 10^{-7}) \frac{lb-mole \text{ min}}{ft^3 \text{ ppmv hr}} \times 1200 \frac{hr}{yr} \times [0.03]$$

3429

$$3430 \quad E(PCE) = 0.67629 \frac{lb}{hr} \times 1200 \frac{hr}{yr} \times [0.03]$$

$$3431 \quad E(PCE) = 811.5539 \frac{lb}{yr} \times [0.03]$$

$$3432 \quad \boxed{E(PCE) = 24.3 \frac{lb}{yr}}$$

3433

3434 9.6.2 Problem #2 (Air Stripping)

3435 In addition to the emissions resulting from the SVE site on base, the same USAF Base is also
3436 concerned with emissions at an alternate site where JP-8 was removed from groundwater. This
3437 operation was run for about 1120 hours and pumped at an average rate of 45 gal/min. Site
3438 testing indicated that the average concentration of VOCs in the groundwater was
3439 approximately 160 mg/L. Given that the air stripper removal efficiency for this process is 95%
3440 and no control devices are used, calculate the total VOCs emitted into the atmosphere.

3441

3442 **Step 1 – Calculate emissions.** Using Equation 9-2, VOC emissions are calculated as follows:

$$3443 \quad E(Pol) = Q \times C(Pol) \times \frac{RE}{100} \times (5.042 \times 10^{-4}) \times t \times \left[1 - \left(\frac{CE}{100}\right)\right]$$

$$3444 \quad E(VOC) = 45 \frac{gal}{min} \times 160 \frac{mg}{L} \times \frac{95\%}{100\%} \times (5.042 \times 10^{-4}) \frac{lb L min}{mg gal hr} \times 1120 \frac{hr}{yr} \times \left[1 - \left(\frac{0\%}{100\%}\right)\right]$$

$$3446 \quad E(VOC) = 45 \frac{gal}{min} \times 160 \frac{mg}{L} \times 0.95 \times (5.042 \times 10^{-4}) \frac{lb L min}{mg gal hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$3447 \quad E(VOC) = 6840 \frac{gal mg}{min L} \times (5.042 \times 10^{-4}) \frac{lb L min}{mg gal hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$3448 \quad E(VOC) = 3.4487 \frac{lb}{hr} \times 1120 \frac{hr}{yr} \times [1]$$

$$3449 \quad \boxed{E(VOC) = 3862.5 \frac{lb}{yr}}$$

3450

3451 **9.7 References**

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3463 N.C

3464

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3465

3466 10 LAND USE CHANGE

3467 ➤ *Carbon Dioxide Sequestration*

3468

3469 10.1 Introduction

3470 DoD Directive 4715.21, Climate Change Adaptation and Resilience establishes a new policy to
3471 assess and manage risks associated with the impacts of climate change and ensures that climate
3472 change is incorporated into all aspects of military planning. The policy states that DoD must
3473 be able to adapt current and future operations to address the impacts of climate change to
3474 maintain an effective and efficient U.S. military. Additionally, the Council on Environmental
3475 Quality (CEQ) recommends assessment of potential climate change impacts when performing
3476 National Environmental Policy Act assessments.

3477

3478 In addition to the criteria pollutants, the EPA has begun to focus attention on GHGs because
3479 they trap heat in the earth's atmosphere, increasing global temperatures. Increases in global
3480 temperatures affect rainfall patterns and surface temperatures, which leads to climate change.
3481 One of the principal GHGs is CO₂. There are many sources of CO₂ emissions, which primarily
3482 include the burning of fossil fuels. To stem the consequences of CO₂ emissions, sequestering
3483 CO₂ has become an important topic.

3484

3485 Sequestration is the environment's natural ability to remove and store air pollutants such as
3486 CO₂. Assessing CO₂ sequestration changes associated with an action has become a surrogate
3487 for assessing potential impacts of an action on climate change. This chapter addresses
3488 quantifying CO₂ sequestration, or the loss of sequestration (sequestration forfeiture) associated
3489 with changing land use.

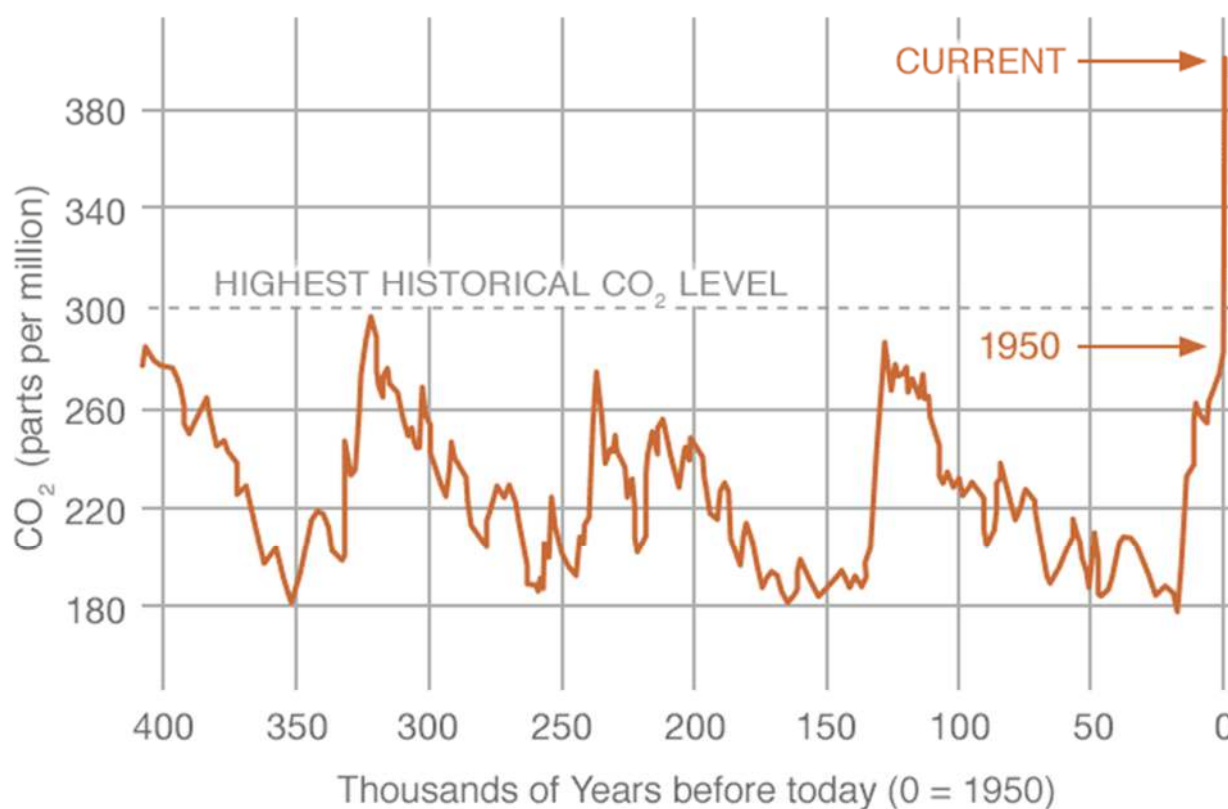
3490

3491 10.2 Background Information

3492 CO₂ is an important heat trapping gas, which is released through human activities such as
3493 deforestation and burning fossil fuels, as well as natural processes such as respiration and
3494 volcanic eruptions. The carbon found in atmospheric CO₂ is just a tiny fraction of earth's total
3495 carbon reserves. Carbon is also found in rocks, oceans, fossil fuel deposits, and all living
3496 things. The movement of carbon atoms between these reservoirs is known as the carbon cycle.
3497 Carbon leaves the atmosphere when photosynthesizing organisms such as plants, algae, and
3498 some kinds of bacteria pull it out of the air and combine it with water to form carbohydrates. It
3499 gets returned to the atmosphere as CO₂ when humans and other animals breathe it out, or when
3500 plants die and decompose. Sometimes, instead of rotting and releasing their carbon back into
3501 the atmosphere, photosynthesizers get buried deep underground, locking their carbon away in
3502 the earth for millions of years.

3503

3504 Over time, this balance of intake and emission has kept the amount of CO₂ in the atmosphere
3505 relatively cyclic with the maximum CO₂ level below 300 ppm. However, the amount of CO₂
3506 in the atmosphere has increased steadily since the beginning of the Industrial Revolution, with
3507 CO₂ concentrations rising especially sharply in the latter half of the 20th century. Figure 10-1.
3508 Carbon Dioxide Level Over Time, shows CO₂ levels during the last three glacial cycles, as
3509 reconstructed from ice cores. Since 1950 there has been a dramatic increase in CO₂ levels well
3510 beyond the 300 ppm of the past natural cycles which has been causally linked to human
3511 activities and climate change. Human activities associated with changes to land use may
3512 directly impact local air quality by reducing the environment's natural ability to sequester
3513 (remove and store) air pollutants.



3514 SOURCE: https://climate.nasa.gov/system/charts/15_co2_left_061316.gif (Data source: Reconstruction from ice cores. Credit:
3515 NOAA).
3516

3517 **Figure 10-1. Carbon Dioxide Level Over Time**

3518 Solar radiation and the presence of GHGs in Earth's atmosphere play a large role in the
3519 temperature of the planet. Solar radiation passes through the atmosphere and warms Earth's
3520 surface. Naturally occurring GHGs, such as CO₂, CH₄ and even water vapor (H₂O) create an
3521 insulating layer in the atmosphere, which helps prevent the heat from escaping Earth. This
3522 makes it possible for the Earth to be warm enough to sustain life.

3523

3524 This guidance contains methodologies which may be used to calculate the sequestration or
3525 forfeiture (loss) of sequestration of CO₂ that occurs when the use of a parcel of land is changed
3526 for NEPA reviews. An example of a land use change is when a parcel of grassland becomes a
3527 forestland through the planting of trees.

3528

3529 **10.3 Calculation Methodology**

3530 The CEQ and DoD guidance falls short of recommending a methodology for agencies to use
3531 when addressing land use change in NEPA reviews. In this regard, agencies are tasked to
3532 determine the best methodology that fits their needs. To quantify the effect of land use change
3533 on GHGs, an appropriate methodology would consider the amount of CO₂ that is captured
3534 from the atmosphere and stored as carbon in plant material during photosynthesis.

3535 Additionally, an appropriate methodology would consider all carbon pools, such as above
3536 ground plant material, below ground plant material, and soil. Furthermore, different types of
3537 land (forest, grassland, wetlands, and agriculture) store carbon at different rates depending on
3538 climatic conditions and vegetation type, therefore an appropriate methodology would consider
3539 climate and vegetation type as well. The U.S. Geological Survey (USGS) has published three
3540 reports that assess the carbon fluxes (changes) among different land types in different regions
3541 of the United States. To date, this USGS data is the most appropriate to use for calculating the
3542 carbon or CO₂ flux of different land use changes.

3543

3544 **10.3.1 USGS Methodology Background**

3545 In 2007, Congress directed the Department of the Interior to develop a methodology to assess
3546 the amount of carbon stored in ecosystems, the capacity of ecosystems to sequester carbon, and
3547 the rate of GHG fluxes in and out of the ecosystems. In response to that directive, the USGS
3548 has produced three reports to fulfill the requirements of section 712 of the Energy
3549 Independence and Security Act (EISA) of 2007. These reports divided the continental United
3550 States into three regions. Western Region, Eastern Region, and Great Plains Region.

3551

3552 For these regional assessments, three biogeochemical models were run in an ensemble fashion
3553 on the General Ensemble Biogeochemical Modeling System (GEMS) platform. These
3554 biogeochemical models were used to simulate ecosystem biogeochemical cycles and estimate
3555 carbon flux values. The biogeochemical models used are the Century version 4.0, the Erosion
3556 Deposition Carbon Model (EDCM), and the Land Greenhouse Gas Accounting Tool (LGAT).
3557 Included in these USGS reports is an assessment of the amount of carbon dioxide sequestered
3558 by various land uses, such as forest land, grassland, wetland, and agriculture for each region. It
3559 is these values that serve as the basis for this methodology.

3560

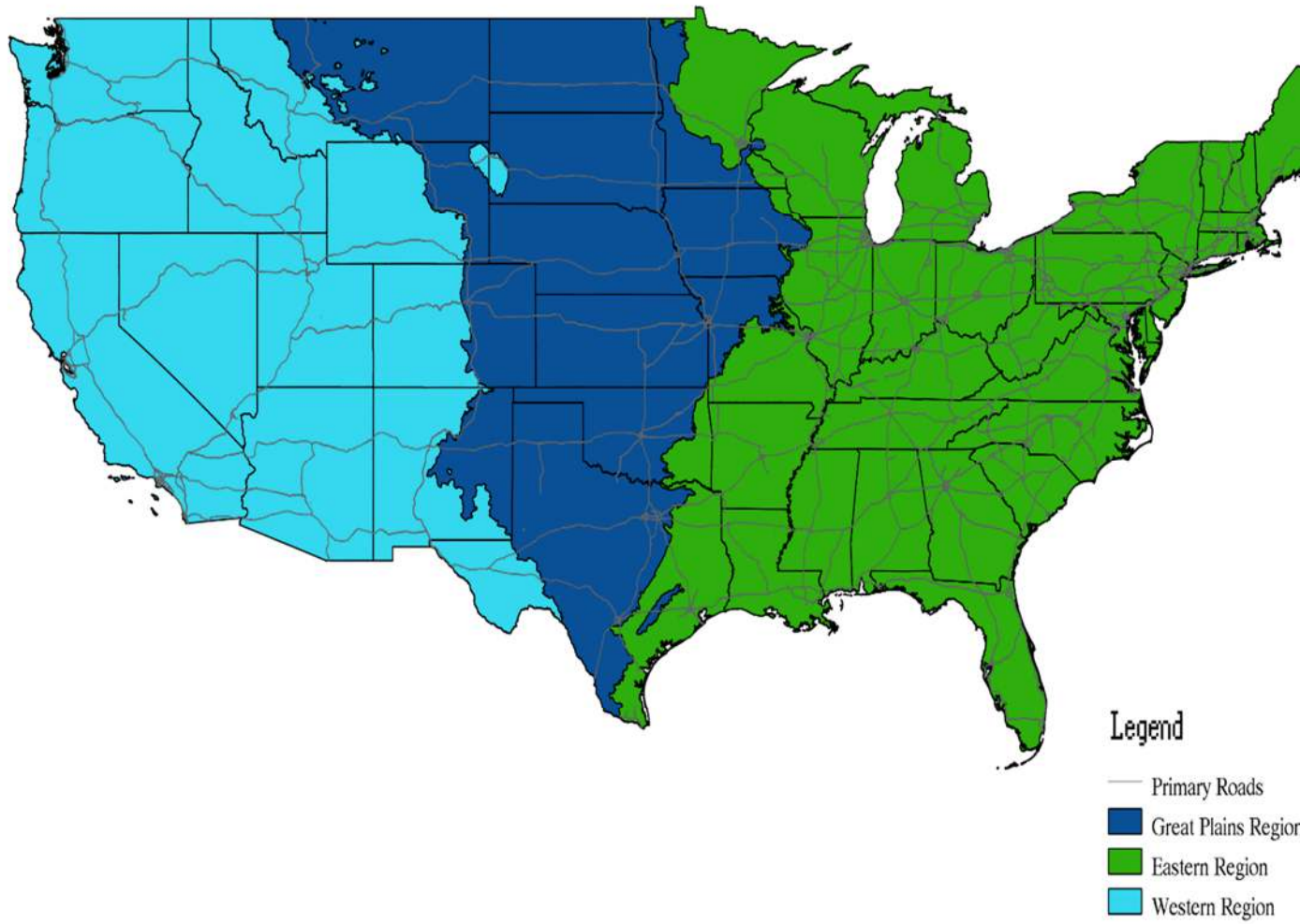
3561 **10.3.2 Sequestration Factors**

3562 Sequestration factors were derived based on the USGS regional reports for use when
 3563 calculating sequestration or sequestration forfeiture from land use change (see Table 10-1.
 3564 Sequestration Factors for Various Regions and Land Types). These factors represent how
 3565 much CO₂ a type of land scenario sequesters per year in each specific region. Information
 3566 regarding Alaska is in development. These regions are shown in Figure 10-2. Regional Map
 3567 for Land Use Change Sequestration Factors.

3568 **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

- 3569
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 3578 c. SOURCE: Zhu, Zhiliang, and Reed, B. C., eds., 2014, Baseline and Projected Future Carbon Storage and Greenhouse-Gas
 3579 Fluxes in Ecosystems of the Western United States: U.S. Geological Survey Professional Paper 1804, 204 p.,
 3580 <http://dx.doi.org/10.3133/pp1804>.



3581

3582

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

3583 10.3.3 Calculating Sequestration

3584 The USGS methodology can be used to calculate the carbon dioxide sequestration of a land use
 3585 change. This methodology is designed to be used for instances when land is being changed
 3586 from one use to another, such as a grassland being converted into a forestland. Sequestration,
 3587 both gains and losses from changing land use, can be calculated using Equation 10-1. Positive
 3588 values for sequestration change indicate that the land use change has increased the
 3589 sequestration of the land. Negative values indicate that the land use change resulted in a
 3590 decrease of sequestration, meaning less pollutants such as CO₂ are removed and stored. Use
 3591 Figure 10-2 to identify the ecoregion that the land use change is occurring in and then use the
 3592 sequestration factors from Table 10-1 **Error! Reference source not found.** as inputs into
 3593 Equation 10-1 to calculate the change in sequestration.

$$3594 \quad \Delta S = (A_f \times SF_f) - (A_i \times SF_i)$$

3595 **Equation 10-1**

3596 Where,

- 3597 ΔS = Sequestration change (lb CO₂/yr)
 3598 A_f = Area of land after land use change (acre)
 3599 SF_f = Sequestration factor of land type after change (lb CO₂/acre-yr)
 3600 A_i = Area of land before land use change (acre)
 3601 SF_i = Sequestration factor of land type before change (lb CO₂/acre-yr)

3603 10.4 Example Problems

3604 10.4.1 Problem #1 (Increase in Sequestration)

3605 A USAF Base in Florida is considering converting 30 acres of grassland into forestland.
 3606 Determine the sequestration change.

3607
 3608 **Step 1 – Determine the region the land use change is occurring.** Since the USAF Base is in
 3609 Florida, it is in the Eastern Region.

3610
 3611 **Step 2 – Select the appropriate sequestration factors.** For the Eastern Region, the
 3612 sequestration factor for grassland and forestland (as given in Table 10-1) are **1341.2 lb**
 3613 **CO₂/acre-year** and **5070.6 lb CO₂/acre-year**, respectively.

3614
 3615 **Step 3 – Calculate the sequestration change.** Use the sequestration factors from Step 2 and
 3616 Equation 10-1 to calculate this value.

$$3617 \quad \Delta S = (A_f \times SF_f) - (A_i \times SF_i)$$

$$3618 \quad \Delta S = \left(30 \text{ acres} \times 5070.6 \frac{\text{lb CO}_2}{\text{acre yr}} \right) - \left(30 \text{ acres} \times 1341.2 \frac{\text{lb CO}_2}{\text{acre yr}} \right)$$

$$3619 \quad \Delta S = \left(152,118 \frac{\text{lb CO}_2}{\text{yr}}\right) - \left(40,236 \frac{\text{lb CO}_2}{\text{yr}}\right)$$

$$3620 \quad \boxed{\Delta S = 111,882 \frac{\text{lb CO}_2}{\text{yr}}}$$

3621

3622 **10.4.2 Problem #2 (Decrease in sequestration/forfeiture)**

3623 A USAF Base in Utah has decided to clear 25 acres of forestland and convert this to grassland.

3624 Determine the change in sequestration.

3625

3626 **Step 1 – Determine the region the land use change is occurring.** Since the USAF Base is in
3627 Utah, it is in the Western Region.

3628

3629 **Step 2 – Select the appropriate sequestration factors.** For the Western Region, the
3630 sequestration factor for grassland and forestland (as given in Table 10-1) are **523.4 lb**
3631 **CO₂/acre-year** and **2355.4 lb CO₂/acre-year**, respectively.

3632

3633 **Step 3 - Calculate the sequestration change.** Use the sequestration factors from Step 2 and
3634 Equation 10-1 to calculate this value.

$$3635 \quad \Delta S = (A_f \times SF_f) - (A_i \times SF_i)$$

$$3636 \quad \Delta S = \left(25 \text{ acres} \times 523.4 \frac{\text{lb CO}_2}{\text{acre yr}}\right) - \left(25 \text{ acres} \times 2355.4 \frac{\text{lb CO}_2}{\text{acre yr}}\right)$$

$$3637 \quad \Delta S = \left(13,085 \frac{\text{lb CO}_2}{\text{yr}}\right) - \left(58,885 \frac{\text{lb CO}_2}{\text{yr}}\right)$$

$$3638 \quad \boxed{\Delta S = -45,800 \frac{\text{lb CO}_2}{\text{yr}}}$$

3639

3640 **10.4.3 Problem #3 (Decrease in sequestration/forfeiture)**

3641 A USAF Base in Utah has decided to clear 25 acres of forestland and convert this to into a 5-
3642 acre office building and a 15-acre parking lot with the remaining 5 acres being grass.

3643 Determine the change in sequestration.

3644

3645 **Step 1 – Determine the region the land use change is occurring.** Since the USAF Base is in
3646 Utah, it is in the Western Region.

3647

3648 **Step 2 – Select the appropriate sequestration factors.** For the Western Region, the
3649 sequestration factor for grassland and forestland (as given Table 10-1) are **523.4 lb CO₂/acre-**

3650 **year and 2355.4 lb CO₂/acre-year**, respectively. The building and parking lot (20 acres total)
 3651 are impervious surfaces; therefore, the sequestration factor is **0.0 lb/CO₂/acre-year**.

3652

3653 **Step 3 - Calculate the sequestration change.** Use the sequestration factors from Step 2 and
 3654 Equation 10-1 to calculate this value.

3655
$$\Delta S = (A_f \times SF_f) - (A_i \times SF_i)$$

3656
$$\Delta S = \left[\left(5 \text{ acres} \times 523.4 \frac{\text{lb CO}_2}{\text{acre yr}} \right) + \left(20 \text{ acres} \times 0.0 \frac{\text{lb CO}_2}{\text{acre yr}} \right) \right] - \left(25 \text{ acres} \times \right.$$

 3657
$$\left. 2355.4 \frac{\text{lb CO}_2}{\text{acre yr}} \right)$$

3658
$$\Delta S = \left(2,617 \frac{\text{lb CO}_2}{\text{yr}} \right) - \left(58,885 \frac{\text{lb CO}_2}{\text{yr}} \right)$$

3659
$$\Delta S = -56,268 \frac{\text{lb CO}_2}{\text{yr}}$$

3660

3661 **10.5 References**

- 3662 CEQ 2016. Final Guidance for Federal Departments and Agencies on Consideration of
3663 Greenhouse Gas Emissions and the Effects of Climate Change in National Environmental
3664 Policy Act Reviews, Council on Environmental Quality, 81 FR 51866
- 3665 Zhu, Zhiliang, ed., Bouchard, Michelle, Butman, David, Hawbaker, Todd, Li, Zhengpeng, Liu,
3666 Jinxun, Liu, Shuguang, McDonald, Cory, Reker, Ryan, Sayler, Kristi, Sleeter, Benjamin, Sohl,
3667 Terry, Stackpoole, Sarah, Wein, Anne, and Zhu, Zhiliang, 2011, Baseline and Projected Future
3668 Carbon Storage and Greenhouse-Gas Fluxes in the Great Plains Region of the United States:
3669 U.S. Geological Survey Professional Paper 1787, 28 p. (Also available at
3670 <http://pubs.usgs.gov/pp/1787/>.)
- 3671 Zhu, Zhiliang, and Reed, B. C., eds., 2012, Baseline and Projected Future Carbon Storage and
3672 Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey
3673 Professional Paper 1797, 192 p. (Also available at <http://pubs.usgs.gov/pp/1797/>.)
- 3674 Zhu, Zhiliang, and Reed, B. C., eds., 2014, Baseline and Projected Future Carbon Storage and
3675 Greenhouse-Gas Fluxes in Ecosystems of the Western United States: U.S. Geological Survey
3676 Professional Paper 1804, 204 p., <http://dx.doi.org/10.3133/pp1804>
- 3677

3678
3679

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3680 11 WILDFIRES AND PRESCRIBED BURNING

3681 ➤ *Fugitive Source*

3682

3683 11.1 Introduction

3684 Wildfires and prescribed burns are large combustions of **forest, grassland, brushland, or land**
3685 **sown to crops. Forest fire, brush fire, etc., are often used to describe specific types of**
3686 **wildfires and prescribed burns; their usage varies according to the characteristics of the**
3687 **fire and the region in which it occurs.**

3688

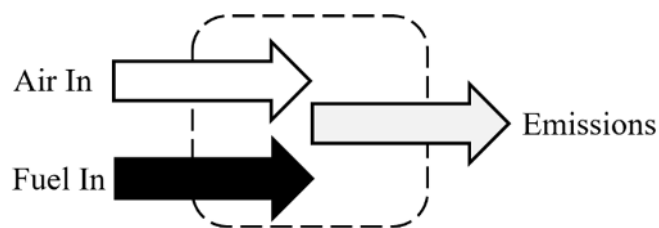
3689 A wildfire is a large-scale natural combustion process that consumes various ages, sizes, and
3690 types of flora growing outdoors in a geographical area. Consequently, wildfires are potential
3691 sources of large amounts of air pollutants. Emissions from wildfires may travel large distances
3692 and contribute to the release of over 10 tons/km² of CO₂ annually in the United States (Liu
3693 2005).

3694

3695 Prescribed burning is a land treatment, used under controlled conditions, to accomplish natural
3696 resource management objectives. It is one of several land treatments, used individually or in
3697 combination, including chemical and mechanical methods. Prescribed fires are conducted
3698 within the limits of a fire plan and prescription that describes both the acceptable range of
3699 weather, moisture, fuel, and fire behavior parameters, and the ignition method to achieve the
3700 desired effects. Prescribed fire is a cost-effective and ecologically sound tool for forest, range,
3701 and wetland management. Its use reduces the potential for destructive wildfires and thus
3702 maintains long-term air quality. Also, the practice removes logging residues, controls insects
3703 and disease, improves wildlife habitat and forage production, increases water yield, maintains
3704 natural succession of plant communities, and reduces the need for pesticides and herbicides.
3705 The major air pollutant of concern is the smoke produced.

3706

3707 **Wildfires and prescribed burn operations result in the fugitive emissions of criteria**
3708 **pollutants and greenhouse gases.** A simple control volume describing emissions resulting
3709 from wildfires is provided in Figure 11-1



3710

3711 **Figure 11-1. Simplified Wildfire & Prescribed Burning Control Volume**

3712 **11.1.1 Fuel Loading**

3713 Both fuel type (composition) and fuel loading on the fire process cannot be overemphasized in
3714 estimating emissions from wildfires and prescribed burns. Fuel materials typically include
3715 downed trees, fallen branches, decayed matter on the forest floor (duff), small trees, shrubs,
3716 and grasses. Tree crowns (branch wood and foliage) can also be burned in wildfires and
3717 prescribed fires. The fuel consumption in a fire will depend not only on the total pre-burn fuel
3718 loading, but also on the relative composition of the available fuel (amounts of the different fuel
3719 types), and on the fuel condition.

3720

3721 There are several methods available to estimate fuel loadings and characteristics; however, the
3722 most accurate method is to measure the fuel loading. The Forest Service has developed
3723 guidelines for measuring the amount of fuel materials. The line intersect method has been used
3724 to develop information on fuel loading and characteristics in advance of a prescribed burn. In
3725 this method, a surveyor walks a line through the forest, measuring each downed log that is
3726 intersected, and gathering information on other debris and fuel material on the forest floor.
3727 Piles are measured, and samples of brush may be clipped and weighed. Unfortunately, these
3728 methods are very resource intensive for a regional scale inventory. In addition, they must be
3729 used before the fire occurs. (Brown 1974 and Hardy 1996)

3730

3731 For the sake of conformity and convenience, default estimated fuel loadings anticipated for the
3732 vegetation in the U. S. Forest Service Regions are presented in Table 11-1; however, site-
3733 specific fuel loading data is always preferred. It is strongly urged conduct site-specific fuel
3734 loading measurements or to contact that state's federal land management agencies and state
3735 forestry agencies that conduct prescribed burning to obtain the best information on such
3736 activities.

3737 **11.1.2 Forest Regions**

3738 The U.S. Forest Service has established nine Forest Service Regions; numbered 1 through 10
3739 (Region 7 was eliminated in 1965 when the current Eastern Region was created from the
3740 former Eastern and North Central regions). These regions are broad geographic areas, usually
3741 including several states, encompassing 155 National Forests and 20 National Grasslands.
3742 These lands include a vast treasure of diverse landscapes, ecosystems, fauna, and flora. The
3743 Air Force further divides two Forest Service Regions (Regions 9 and 10) into subregions based
3744 on geographical areas and forest species (see Figure 11-2):

3745

3746 **Region 1, Northern Region:** The Northern Forest Service Region is within the Rocky
3747 Mountain Geographic Area of the U.S. which includes Montana, northern Idaho, North
3748 Dakota, northwestern South Dakota, northeastern Washington, and northwestern Wyoming.

3749

3750 **Region 2, Rocky Mountain Region:** The Rocky Mountain Forest Service Region is within
3751 the Rocky Mountain Geographic Area of the U.S. which includes Colorado, Nebraska, Kansas,
3752 most of Wyoming and most of South Dakota.

3753

3754 **Region 3, Southwestern Region:** The Southwestern Forest Service Region is within the
3755 Rocky Mountain Geographic Area of the U.S. which includes Arizona and New Mexico.

3756

3757 **Region 4, Intermountain Region:** The Intermountain Forest Service Region is within the
3758 Rocky Mountain Geographic Area of the U.S. which includes primarily southern Idaho,
3759 Nevada, Utah, and western Wyoming.

3760

3761 **Region 5, Pacific Southwest Region:** The Pacific Southwest Forest Service Region is within
3762 the California & Hawaii region of the Pacific Geographic Area of the U.S. which includes
3763 California and Hawaii.

3764

3765 **Region 6, Pacific Northwest Region:** The Pacific Northwest Region is within the norther
3766 region of the Pacific Geographic Area which includes Oregon and Washington.

3767

3768 **Region 8, Southern Region:** The Southern Region is within the Southern Geographic Area of
3769 the U.S. which includes Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana,
3770 Mississippi, North Carolina, South Carolina, Tennessee, Texas, Oklahoma, and Virginia.

3771

3772 **Region 9(a), Eastern – Northern Region:** The Eastern Region is within the Eastern
3773 Geographic Area of the U.S. which includes Connecticut, Delaware, Main, Maryland,
3774 Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island,
3775 Vermont, and West Virginia.

3776

3777 **Region 9(b), Eastern – Central Region:** The Northern Central Region is within the Northern
3778 Central Geographic Area of the U.S. which includes Illinois, Indiana, Iowa, Michigan,
3779 Minnesota, Missouri, Ohio, and Wisconsin.

3780

3781 **Region 10(a), Alaska – Northern Region:** The Alaska – Northern Region is within the
3782 norther and western areas of Alaska that is part of the Pacific Geographic Area of the U.S. The
3783 Alaska – Northern Region includes the following boroughs (counties): Nome, North Slope, and
3784 the Northwest Arctic.

3785

3786 **Region 10(b), Alaska – Coastal Region:** The Alaska – Coastal Region is within the coastal
3787 areas of Alaska that is part of the Pacific Geographic Area. The Alaska – Coastal Region
3788 includes the following boroughs (counties): Aleutians East, Aleutians West, Anchorage,
3789 Bethel, Bristol Bay, Denali, Dillingham, Haines, Juneau, Kenai Peninsula, Ketchikan Gateway,

3790 Kodiak Island, Lake and Peninsula, Matanuska Susitna, Prince Wales Ketchikan, Sitka,
 3791 Skagway Hoonah Angoon, Valdez Cordova, Wade Hampton, Wrangell Petersburg, and
 3792 Yakutat.

3793

3794 **Region 10(c), Alaska – Interior Region:** The Alaska – Interior Region is within the norther
 3795 and western areas of Alaska that is part of the Pacific Geographic Area. The Alaska – Interior
 3796 Region includes the following boroughs (counties): Yukon Koyukuk, Fairbanks North Star,
 3797 and Southeast Fairbanks.

3798

3799

Table 11-1. U.S. Forest Service Forest Regions

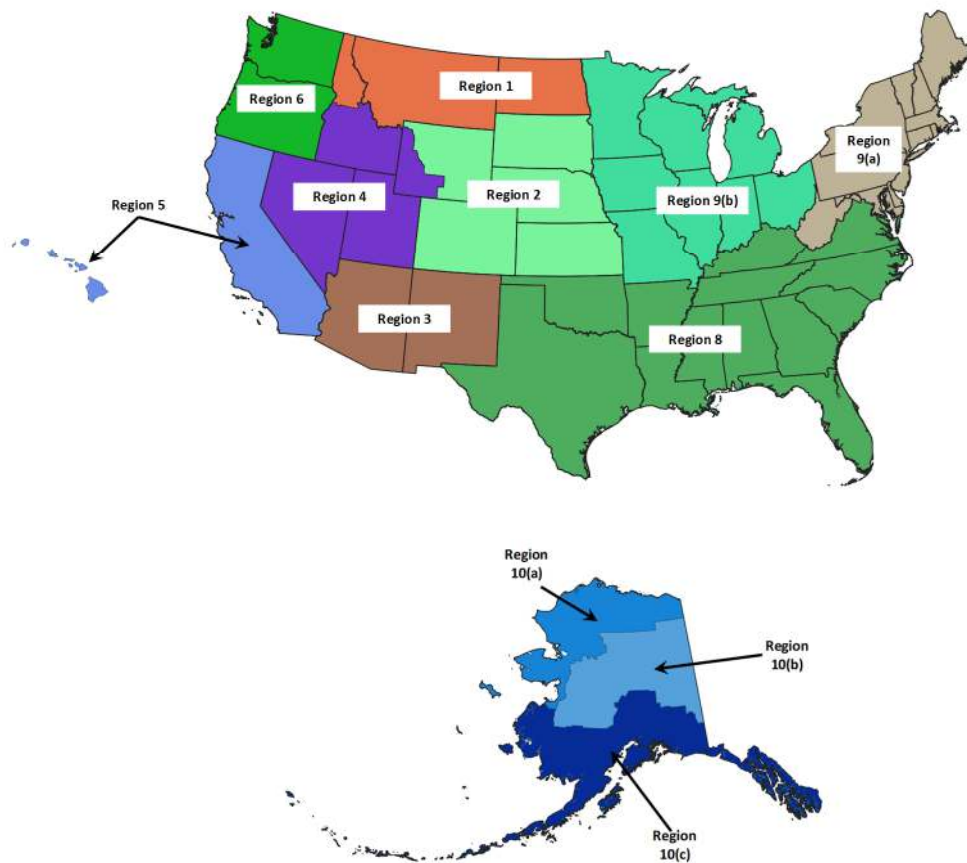
3800

Forest Region:	Geographical Area:	States Within	Fuel Loading (ton/acre)
1	Rocky Mountain	Montana, northern Idaho, North Dakota, northwestern South Dakota, northeastern Washington, and northwestern Wyoming	60
2	Rocky Mountain	Colorado, Nebraska, Kansas, most of Wyoming and most of South Dakota	30
3	Rocky Mountain	Arizona and New Mexico	10
4	Rocky Mountain	Southern Idaho, Nevada, Utah, and western Wyoming	8
5	Pacific Southwest	California and Hawaii	18
6	Pacific Northwest	Oregon and Washington	60
8	Southern	Alabama, Arkansas, Florida, Georgia, Kentucky, Louisiana, Mississippi, North Carolina, South Carolina, Tennessee, Texas, Oklahoma, and Virginia	9
9(a)	Eastern	Connecticut, Delaware, Main, Maryland, Massachusetts, New Hampshire, New Jersey, New York, Pennsylvania, Rhode Island, Vermont, and W. Virginia	11
9(b)	Northern Central	Illinois, Indiana, Iowa, Michigan, Minnesota, Missouri, Ohio, and Wisconsin	11
10(a)	Pacific Northwest	Alaska northern counties	16
10(b)	Pacific Northwest	Alaska coastline counties	60
10(c)	Pacific Northwest	Alaska interior counties	11

3801

3802 SOURCE: Section 13.1 – “Wildfires and Prescribed Burning,” Compilation of Air Pollutant Emission Factors – Volume I:

3803 Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.



3804

3805
3806

3807

Figure 11-2. Map of U.S. Forest Service Forest Regions

3808

3809 **11.2 Wildfires**

3810 Wildfires are uncontrolled fires that burn in the wildland vegetation (forests, grasslands,
 3811 savannas, and other ecosystems), often in rural areas. The size, intensity, and occurrence of
 3812 wildfires depends directly on the meteorological conditions, the species of vegetation, moisture
 3813 content of the vegetation, and the weight of consumable fuel per acre (available fuel loading).
 3814 Once a fire begins, the dry combustible material is consumed first. If the energy release is
 3815 large and of sufficient duration, the drying of green, live material occurs, with subsequent
 3816 burning of this material as well. Under proper environmental and fuel conditions, this process
 3817 may initiate a chain reaction that results in a widespread conflagration.

3818

3819 **11.2.1 Wildfire Emission Factors**

3820 Estimating emissions from wildfires is difficult because the amount of pollution emitted into
 3821 the atmosphere is likely based on the intensity and direction of the wildfire, which are

3822 influenced by several variables. These variables include, but are not limited to, wind velocity,
 3823 ambient temperature, relative humidity, and topography. However, the most important factor
 3824 in wildfire intensity is likely the fuel itself – specifically the vegetation species and moisture
 3825 content. The regions developed by the USFS have their own set of criteria pollutant Emission
 3826 Factors (EFs). These EFs were developed for each U.S. Forest Service Region based on the
 3827 expected vegetation and fuel loading factor. These EFs are provided in Table 11-2 and Table
 3828 11-3.

3829 **Table 11-2. Criteria Pollutant Emission Factors for Wildfires**

Emission Factors (lb/ton)						
NO _x	CO	SO _x	Pb	VOC	PM ₁₀ ^a	PM _{2.5} ^b
4	140	---	---	24	17.00	15.11

3830
 3831 SOURCE: Section 13.1 – “Wildfires and Prescribed Burning,” Compilation of Air Pollutant Emission Factors –
 3832 Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.
 3833 a. Source document provides emission factor for total PM; total PM conservatively assumed to be equal to PM₁₀.
 3834 b. Source document provides emission factors for PM. These values calculated using the PM₁₀ and PM_{2.5} fraction
 3835 from Krause, Mike and Steve Smith, “Methodology to Calculate Particulate Matter (PM) 2.5 and PM 2.5
 3836 Significance Thresholds,” South Coast Air Quality Management District, October 2006.

3837 **Table 11-3. Greenhouse Gas Emission Factors for Wildfires**

Emission Factors (lb/ton)			
CO ₂ ^a	N ₂ O	CH ₄	CO ₂ e ^a
---	0.46	12.2	442

3838
 3839 SOURCE: Section 13.1 – “Wildfires and Prescribed Burning,” Compilation of Air Pollutant Emission Factors –
 3840 Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.
 3841 a. CO₂e calculated by summing the product of the emission factors for N₂O, and CH₄ and their respective Global
 3842 Warming Potentials (GWP). Emissions of CO₂ from this source as well as other biogenic sources are part of
 3843 the carbon cycle, and as such are typically not included in greenhouse gas emission inventories.
 3844 b.

3845 11.2.2 Wildfire Emission Calculation

3846 The importance of both fuel type and fuel loading on the fire process cannot be
 3847 overemphasized. Wildfire emissions are estimated from the fuel loading (L), the area burned,
 3848 and pollutant-specific EFs:

$$3849 \quad E_{Pol} = \frac{L \times EF_{Pol} \times A}{2,000}$$

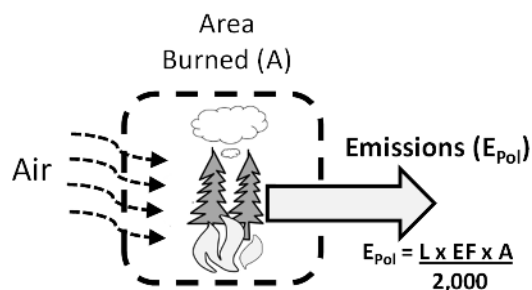
3850 *Equation 11-1*

3851 Where:

3852
 3853 E_{Pol} = Total Emissions of Specified Pollutant (ton)
 3854 L = Fuel Loading Consumed (ton/acre, mass of forest fuel/unit land area),

3855 See Table 11-1 for default values.
 3856 EF_{Pol} = Emission Factor for Specified Pollutant (lb/ton)
 3857 See Table 11-2 and Table 11-3.
 3858 A = Area of Land Burned (acre)
 3859 2,000 = Conversion Factor from lb to ton (lb/ton)

3860
 3861 A detailed control volume describing the calculation of emissions from wildfires is depicted in
 3862 Figure 11-3



3863
 3864 **Figure 11-3. Wildfire Control Volume**

3865
 3866 **11.2.3 Wildfire Example Problem**

3867 Last year, a wildfire consumed 6.5 acres of land at Eglin AFB. Calculate the CO, VOC, PM₁₀,
 3868 and CO_{2e} emissions from this wildfire.

3869
 3870 **Step 1 – Determine the fuel loading factor.** Since the occurred at Eglin AFB, which is in
 3871 Florida, the fire was within the Southern Forest Region. The first step involves determining
 3872 the fuel loading factor which, according to Table 11-2 for the Southern Forest Region the
 3873 default fuel loading factor is 9 ton/acre.

3874
 3875 **Step 2 – Determine the emission factors.** According to Table 11-2 the EFs for CO, VOC,
 3876 PM₁₀, and CO_{2e} are **140, 24, 17, and 442.08 lb/ton**, respectively.

3877
 3878 **Step 3 – Calculate emissions.** Using the area burned (A), the fuel loading factor (L), the EFs
 3879 recorded in Step 2, and the pound to ton conversion factor. The emissions of each pollutant are
 3880 calculated as follows:

$$E_{Pol} = \frac{L \times EF_{Pol} \times A}{2,000}$$

3881
 3882
 3883
$$E_{CO} = \frac{9 \frac{ton}{acre} \times 140 \frac{lb}{acre} \times 6.5 acre}{2,000 lb/ton}$$

3884 $E(CO) = 4.1 \text{ ton}$

3885

3886
$$E_{VOC} = \frac{9 \frac{\text{ton}}{\text{acre}} \times 24 \frac{\text{lb}}{\text{acre}} \times 6.5 \text{ acre}}{2,000 \text{ lb/ton}}$$

3887 $E(VOC) = 0.7 \text{ ton}$

3888

3889

3890
$$E_{PM10} = \frac{9 \frac{\text{ton}}{\text{acre}} \times 17 \frac{\text{lb}}{\text{acre}} \times 6.5 \text{ acre}}{2,000 \text{ lb/ton}}$$

3891 $E(PM10) = 0.5 \text{ ton}$

3892

3893

3894
$$E_{CO_2e} = \frac{9 \frac{\text{ton}}{\text{acre}} \times 442.08 \frac{\text{lb}}{\text{acre}} \times 6.5 \text{ acre}}{2,000 \text{ lb/ton}}$$

3895 $E(CO_2e) = 12.9 \text{ ton}$

3896

3897 **11.3 Prescribed Burning**

3898 Prescribed burning is a cost-effective method for the management of forests, ranges, and
 3899 wetlands to accomplish natural resource management objectives. These objectives may
 3900 include the treatment of an area to reduce the potential for wildfires, removing logging
 3901 residues, controlling insects and disease, increasing water yield, or controlling insect
 3902 population and plant overgrowth without the use of herbicides and pesticides. Prescribed
 3903 burning is carried out by adhering to a strict plan that stipulates the required weather conditions
 3904 and burning procedures, including an acceptable temperature range, moisture level, fuel used
 3905 for ignition, and ignition method.

3906 The combustion process associated with prescribed burning is composed of four phases:
 3907 preheating, flaming, glowing, and smoldering. Each phase produces different amounts of
 3908 emissions relative to each other due to the variances in combustion temperatures and
 3909 combustion efficiencies. Therefore, the total emissions from prescribed burning depend on the
 3910 time spent in each phase. The preheating phase is typically the “cleanest” phase since few
 3911 pollutants are emitted into the atmosphere. In contrast, the smoldering phase describes the

3912 portion of the process in which combustion is incomplete and inefficient, resulting in a much
3913 higher ratio of emitted pollutants per fuel consumed. The combustion efficiency varies in the
3914 flaming and glowing phases which, in turn, leads to varying amounts of emitted pollutants.
3915

3916 **11.3.1 Prescribed Burning Fuel Load Composition**

3917 While Table 11-1 provides the default Fuel Loading (weight of consumable fuel per acre) for
3918 each U.S. Forest Service Region, it does not differentiate the various forest species and their
3919 prevalence. Given each species burns differently, a more accurate estimate of emissions can be
3920 accomplished through further defining the relative makeup of the Fuel Loading by species.
3921 Default regional fuel load compositions in Table 11-1, are generally used for general planning
3922 purposes and rough estimates.
3923

3924

Table 11-4. Default Fuel Load Composition by Geographic Area

Forest Species	Forest Region:					
	1	2	3	4	5	6
	Geographical Area:					
	Rocky Mountain	Rocky Mountain	Rocky Mountain	Rocky Mountain	Pacific Southwest	Pacific Northwest
Slash	50%	50%	50%	50%	0%	42%
Conifer - Long Needle	0%	0%	0%	0%	0%	6%
Conifer - Short Needle	20%	20%	20%	20%	15%	29%
Conifer - Mixed	0%	0%	0%	0%	0%	19%
Grassland	20%	20%	20%	20%	10%	0%
Sagebrush	0%	0%	0%	0%	35%	0%
Chaparral	0%	0%	0%	0%	20%	0%
Pinyon/Juniper	0%	0%	0%	0%	20%	0%
Hardwood	0%	0%	0%	0%	0%	4%
Palmetto/Gallberry	0%	0%	0%	0%	0%	0%
Other	10%	10%	10%	10%	0%	0%

Forest Species	Forest Region:					
	8	9(a)	9(b)	10(a)	10(b)	10(c)
	Geographical Area:					
	Southern	Eastern	Northern Central	Pacific Northwest	Pacific Northwest	Pacific Northwest
Slash	20%	50%	50%	42%	42%	42%
Conifer - Long Needle	0%	0%	0%	6%	6%	6%
Conifer - Short Needle	30%	10%	10%	29%	29%	29%
Conifer - Mixed	0%	0%	0%	19%	19%	19%
Grassland	10%	30%	30%	0%	0%	0%
Sagebrush	0%	0%	0%	0%	0%	0%
Chaparral	0%	0%	0%	0%	0%	0%
Pinyon/Juniper	0%	0%	0%	0%	0%	0%
Hardwood	0%	0%	0%	4%	4%	4%
Palmetto/Gallberry	35%	0%	0%	0%	0%	0%
Other	5%	10%	10%	0%	0%	0%

3925

3926

3927

3928

3929

SOURCE: Section 13.1, Table 13.1-4 – “Wildfires and Prescribed Burning,” Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection Agency, October 1996.

3930

3931

3932

3933

3934

The defaults are regional averages based on estimates of the acreage and vegetation type burned and may not reflect prescribed burning activities in a given state. Also, the regions identified are broadly defined, and the mix of vegetation and acres burned within a given state may vary considerably from the regional averages provided. Generally, these default values should not be used to develop emission inventories and control strategies.

3935

11.3.2 Prescribed Burning Emission Factors

3936

3937

AP-42 provides several EFs for prescribed burning in Section 11.1. Details regarding each source are provided in the following sections.

3938

Table 11-5. Criteria Pollutant Emission Factors for Prescribed Burns

Fuel	Emission Factors (lb/ton)						
	NOx ^a	CO	SO ₂ ^a	Pb	VOC ^b	PM ₁₀	PM _{2.5}
Slash	4.80	153.00	2.10	0.00	8.00	12.40	10.80
Conifer - Long Needle	4.80	178.00	2.10	0.00	6.40	25.00	22.00
Conifer - Short Needle	4.80	312.00	2.10	0.00	7.20	23.10	21.80
Conifer - Mixed	4.80	201.00	2.10	0.00	9.80	20.50	18.80
Grassland ^c	0.00	101.00	0.00	0.00	15.00	15.74	15.01
Sagebrush	4.40	206.00	1.40	0.00	13.70	29.90	26.70
Chaparral	4.40	154.00	1.40	0.00	19.60	20.10	17.30
Pinyon/Juniper	5.10	163.00	2.10	0.00	10.40	20.40	18.70
Hardwood	2.00	256.00	2.10	0.00	10.80	25.00	22.40
Palmetto/Gallberry ^d	4.40	206.00	1.40	0.00	13.70	29.90	26.70
Other (average of all)	3.95	193.00	1.68	0.00	11.46	22.20	20.02

3939

3940

3941

SOURCE (unless otherwise stated): “NWGC Smoke Management Guide for Prescribed Fire,” National Wildfire Coordinating Group (NWCG), Fire Use Working Team, November 2020.

3942

a. SOURCE: Johnson, T.J.; Yokelson, R.J.; Akagi, S.K.; Burling, I.R.; Weise, D.R.; Urbanski, S.P.; Stockwell, C.E.; Reardon, J.; Lincoln, E.N.; Profeta, L.T.M.; Mendoza, A.; Schneider, M.D.W.; Sams, R.L.; Williams, S.D.; Wold, C.E.; Griffith, D.W.T.; Cameron, M.; Gilman, J.B.; Warneke, C.; Roberts, J.M.; Veres, P.; Kuster, W.; de Gouw, J. 2013. Final Report for SERDP Project RC-1649: Advanced Chemical Measurements of Smoke from DoD-Prescribed Burns. Technical Report PNNL-23025. Richland, WA: U.S. Department of Energy, Pacific Northwest National Laboratory. 269p.

3946

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

3947

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

3948

d. Emission factors for sagebrush used.

3949

Pb assumed 0.00, no data available.

3950

3951

3952

3953

3954

3955

Table 11-6. Greenhouse Gas Emission for Prescribed Burns

Fuel	Emission Factors (lb/ton)			
	CO ₂	N ₂ O ^a	CH ₄	CO ₂ e ^b
Slash	3,349	0.46	9.40	3,721
Conifer - Long Needle	3,202	0.46	8.20	3,544
Conifer - Short Needle	3,082	0.46	11.00	3,494
Conifer - Mixed	3,165	0.46	12.80	3,622
Grassland ^c	2,149	0.08	4.50	2,285
Sagebrush	3,126	0.46	11.90	3,561
Chparral	3,257	0.46	5.70	3,537
Pinyon/Juniper	3,231	0.46	12.00	3,668
Hardwood	3,072	0.46	13.20	3,539
Palmetto/Gallberry ^d	3,126	0.46	11.90	3,561
Other (average of all)	3,076	0.42	10.06	3,453

3956

3957

SOURCE (unless otherwise stated): “NWGC Smoke Management Guide for Prescribed Fire,” National Wildfire Coordinating Group (NWCG), Fire Use Working Team, November 2020.

3958

3959

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.

3960

3961

3962

b. CO₂e calculated by summing the product of the emission factors for CO₂, N₂O, and CH₄ and their respective Global Warming Potentials (GWP). The emission factors were taken from 40 CFR 98 Tables C-1 and C-2 and the GWP for CO₂, N₂O, and CH₄ are 1, 298, and 25, respectively.

3963

3964

3965

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

3966

3967

d. Emission factors for sagebrush used.

3968

e.

3969

11.3.3 Prescribed Burning Calculation

3970

The importance of both fuel type and fuel loading on the fire process cannot be

3971

overemphasized. Prescribed Burning emissions are estimated from the fuel loading (L), the

3972

area burned, and pollutant-specific EFs:

3973

3974

$$E_{Pol} = \sum \left(\frac{EF_{Pol} \times S_i \times A}{2,000} \right) = \sum \left(\frac{EF_{Pol} \times L \times (M_i \div 100\%) \times A}{2,000} \right)$$

3975

Equation 11-2

3976

Where:

3977

3978

E_{Pol} = Total Emissions of Specified Pollutant (ton)

3979

EF_{Pol} = Emission Factor for Specified Pollutant (lb/ton)

3980

See Table 11-2 and Table 11-3 for EF values.

3981

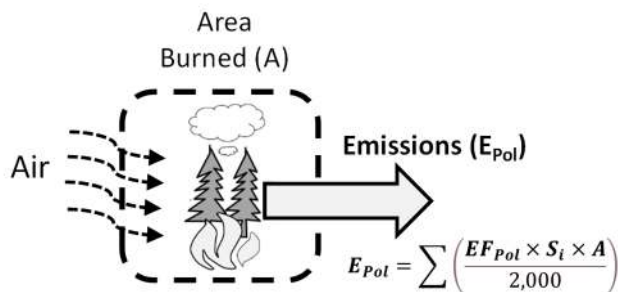
i = Specified Forest Species

3982

M_i = Species Mix or Composition (% of total fuel)

3983 S_i = Species-specific Fuel Loading (ton/acre) = $L \times (M_i \div 100\%)$
 3984 L = Fuel Loading Consumed (ton/acre, mass of forest fuel/unit land area),
 3985 See Table 11-1 for default values.
 3986 A = Area of Land Burned (acre)
 3987 2,000 = Conversion Factor from lb to ton (lb/ton)

3989 A detailed control volume describing the calculation of emissions from wildfires is in Figure
 3990 11-4



3991

3992

Figure 11-4. Prescribed Burning Control Volume

3993 11.3.4 Prescribed Burning Example Problem

3994 Eglin AFB intends to perform a 50-acre prescribed burn. Calculate the NO_x, VOC, and PM_{2.5}
 3995 emissions from this wildfire.

3996

3997 **Step 1 – Determine the fuel loading factor (L).** Since the prescribed burn will occur at Eglin
 3998 AFB, which is in Florida, the fire will be within the Southern Forest Region. The first step
 3999 involves determining the fuel loading factor which, according to Table 11-1 for the Southern
 4000 Forest Region the default fuel loading factor is 9 ton/acre.

4001

4002 **Step 2 – Determine the species mix or composition.** Again, since the prescribed burn will
 4003 occur at Eglin AFB, which is in Florida, the fire will be within the Southern Forest geographic
 4004 area. The next step involves determining the species-specific fuel loading mix, according to
 4005 Table 11-4:

4006 Slash = 20%

4007

4008 Conifer - Short Needle = 30%

4009

4010 Grassland = 10%

4011

4012 Palmetto/Gallberry = 35%

4013

4014 Other = 5%

4015 **Step 3 – Determine the species-specific fuel loading.** Species-specific fuel loading (S_i) is the
4016 relative makeup of the Fuel Loading by species and is calculated as $S_i = L \times (M_i \div 100\%)$.

4017

4018 $S_i(\text{Slash}) = 9 \text{ ton/acre} \times (20\% \div 100\%) = 1.8 \text{ ton/acre}$

4019

4020 $S_i(\text{Conifer - Short Needle}) = 9 \text{ ton/acre} \times (30\% \div 100\%) = 2.7 \text{ ton/acre}$

4021

4022 $S_i(\text{Grassland}) = 9 \text{ ton/acre} \times (10\% \div 100\%) = 0.9 \text{ ton/acre}$

4023

4024 $S_i(\text{Palmetto/Gallberry}) = 9 \text{ ton/acre} \times (35\% \div 100\%) = 3.15 \text{ ton/acre}$

4025

4026 $S_i(\text{Other}) = 9 \text{ ton/acre} \times (5\% \div 100\%) = 0.45 \text{ ton/acre}$

4027

4028 **Step 3 – Determine the emission factors.** According to Table 11-5 and

4029 Table 11-6, the EFs for NO_x, VOC, and PM_{2.5} are:

4030

Fuel	Emission Factors (lb/ton)		
	NO _x	VOC	PM _{2.5}
Slash	4.80	8.00	10.80
Conifer - Short Needle	4.80	7.20	21.80
Grassland	0.00	15.00	15.01
Palmetto/Gallberry	4.40	13.70	26.70
other (average of all)	3.50	10.98	18.58

4031

4032

4033 **Step 4 – Calculate emissions.** Using the area burned (A), the species-specific load (S_i), the
4034 EFs recorded in Step 3, and the pound to ton conversion factor, the emissions of each pollutant
4035 are calculated as follows:

4036

4037

$$E_{Pol} = \sum \left(\frac{EF_{Pol} \times S_i \times A}{2,000} \right)$$

4038

$$E_{NOx} = \frac{4.8 \frac{lb}{acre} \times 1.8 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{4.8 \frac{lb}{acre} \times 2.7 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{0.0 \frac{lb}{acre} \times 0.9 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} \\ + \frac{4.4 \frac{lb}{acre} \times 3.15 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{3.5 \frac{lb}{acre} \times 0.45 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton}$$

4040

4041

$$E_{NOx} = 0.11 \text{ ton}$$

4043

$$E_{VOC} = \frac{8.0 \frac{lb}{acre} \times 1.8 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{7.2 \frac{lb}{acre} \times 2.7 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{15.0 \frac{lb}{acre} \times 0.9 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} \\ + \frac{13.7 \frac{lb}{acre} \times 3.15 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{10.98 \frac{lb}{acre} \times 0.45 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton}$$

4046

$$E_{VOC} = 0.29 \text{ ton}$$

4048

$$E_{PM2.5} = \frac{10.8 \frac{lb}{acre} \times 1.8 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{21.8 \frac{lb}{acre} \times 2.7 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{15.01 \frac{lb}{acre} \times 0.9 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} \\ + \frac{26.7 \frac{lb}{acre} \times 3.15 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton} + \frac{18.58 \frac{lb}{acre} \times 0.45 \frac{ton}{acre} \times 6.5 acre}{2,000 lb/ton}$$

4050

$$E_{PM2.5} = 0.57 \text{ ton}$$

4051

4052

4053 **11.4 References**

- 4054 40 CFR 60 Subpart Cb, “Title 40-Protection of the Environment, Chapter I-Environmental
4055 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4056 Stationary Sources, Subpart Cb-Emissions Guidelines and Compliance Times for Large
4057 Municipal Waste Combustors that are Constructed on or Before September 20, 1995,” U.S.
4058 Environmental Protection Agency
- 4059 40 CFR 60 Subpart Eb, “Title 40-Protection of the Environment, Chapter I-Environmental
4060 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4061 Stationary Sources, Subpart Eb-Standards of Performance for Municipal Waste Combustors for
4062 which Construction is Commenced After June 19, 1996,” U.S. Environmental Protection
4063 Agency
- 4064 40 CFR 60 Subpart AAAA, “Title 40-Protection of the Environment, Chapter I-Environmental
4065 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4066 Stationary Sources, Subpart AAAA-Standards of Performance for Small Municipal Waste
4067 Combustion Units for which Construction is Commenced After August 30, 1999,” U.S.
4068 Environmental Protection Agency
- 4069 40 CFR 60 Subpart BBBB, “Title 40-Protection of the Environment, Chapter I-Environmental
4070 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4071 Stationary Sources, Subpart BBBB-Emissions Guidelines and Compliance Times for Small
4072 Municipal Waste Combustion Units Constructed on or Before August 30, 1999,” U.S.
4073 Environmental Protection Agency
- 4074 40 CFR 60 Subpart CCCC, “Title 40-Protection of the Environment, Chapter I-Environmental
4075 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4076 Stationary Sources, Subpart CCCC-Standards of Performance for Commercial and Industrial
4077 Solid Waste Incineration Units,” U.S. Environmental Protection Agency
- 4078 40 CFR 60 Subpart DDDD, “Title 40-Protection of the Environment, Chapter I-Environmental
4079 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4080 Stationary Sources, Subpart DDDD-Emissions Guidelines and Compliance Times for
4081 Commercial and Industrial Solid Waste Incineration Units,” U.S. Environmental Protection
4082 Agency
- 4083 40 CFR 60 Subpart EEEE, “Title 40-Protection of the Environment, Chapter I-Environmental
4084 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4085 Stationary Sources, Subpart EEEE-Standards of Performance for Other Solid Waste
4086 Incineration Units for which Construction is Commenced After December 9, 2004, or for

- 4087 which Modification or Reconstruction is Commenced on or After June 16, 2006,” U.S.
4088 Environmental Protection Agency
- 4089 40 CFR 60 Subpart FFFF, “Title 40-Protection of the Environment, Chapter I-Environmental
4090 Protection Agency, Subchapter C-Air Programs, Part 60-Standards of Performance for New
4091 Stationary Sources, Subpart FFFF-Emissions Guidelines and Compliance Times for Other
4092 Solid Waste Incineration Units that Commenced Construction on or Before December 9,
4093 2004,” U.S. Environmental Protection Agency
- 4094 40 CFR 60 Subpart C, “Title 40-Protection of the Environment, Chapter I-Environmental
4095 Protection Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas
4096 Reporting, Subpart C-General Stationary Fuel Combustion Sources,” U.S. Environmental
4097 Protection Agency
- 4098 40 CFR 98, “Title 40-Protection of the Environment, Chapter I-Environmental Protection
4099 Agency, Subchapter C-Air Programs, Part 98-Mandatory Greenhouse Gas Reporting, Subpart
4100 C
- 4101 Brown 1974, “Handbook for Inventorying Downed Woody Material;” James K. Brown,
4102 USDA
4103 Forest Service general Technical Report INT-16, Intermountain Forest & Range
4104 Experiment Station, Ogden, Utah; 1974
4105
- 4106 Hardy 1996, “Guidelines for Estimating Volume, Biomass, and Smoke Production for Piled
4107 Slash;” Colin C. Hardy, USDA Forest Service General Technical Report PNW-GTR-364.
4108 Pacific Northwest Research Station, Portland, Oregon; 1996
- 4109 USEPA 1995, Section 2.5-“Open Burning,” Compilation of Air Pollutant Emission Factors –
4110 Volume I: Stationary Point and Area Sources, Fifth Edition, U.S. Environmental Protection
4111 Agency, January 1996
- 4112

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4115 **12 MITIGATION**

4116

4117 **12.1 Introduction**

4118 Mitigation is an important mechanism for agencies to use to avoid, minimize, rectify, reduce,
4119 or compensate the adverse environmental impacts associated with their actions. Federal
4120 Agencies typically rely upon mitigation to reduce environmental impacts through modification
4121 of proposed actions. Agencies also depend on the development of mitigation alternatives
4122 during the NEPA and General Conformity process. Under NEPA, if a proposed action is not
4123 categorically excluded, the Federal agency must determine if the action will have a significant
4124 impact on the environment. The agency must prepare a Finding of No Significant Impact
4125 (FONSI) if it is determined that the action will not have a significant impact on the
4126 environment. The FONSI must present evidence to support this conclusion and state all
4127 mitigation that will be taken, if any. If, however, the agency determines that the action may
4128 have a significant impact on the environment, the agency must prepare an Environmental
4129 Impact Statement (EIS). All mitigation measures not included in the proposed action or
4130 alternatives must be defined within an EIS. After public review, the Record of Decision
4131 (ROD) serves as the final decision of the responsible agency and describes any monitoring and
4132 enforcement programs for mitigation that the agency is committed.

4133

4134 Similarly, under General Conformity (GC), mitigation measures may be required to ensure that
4135 the Federal action conforms to the applicable implementation plan. All mitigation measures
4136 must be identified and an implementation schedule containing explicit timelines must be
4137 described. Mitigation measures may be modified as necessary due to changes in circumstances
4138 if the new measures continue to conform to the applicable implementation plan (40 CFR
4139 93.160). If the emissions cannot be mitigated sufficiently to conform with the implementation
4140 plan, the action cannot proceed.

4141

4142 Mitigation measures minimize adverse environmental effects of a federal action with the
4143 intention of reducing the environmental impacts below a threshold of significance. Ideally, the
4144 mitigation effort would reduce emissions associated with a proposed action below de minimis
4145 thresholds. To demonstrate the reduction results in emissions below de minimis thresholds, the
4146 total direct and indirect emissions from the proposed action must be fully offset with the
4147 affected nonattainment or maintenance area so that there is no net increase in emissions of the
4148 pollutants of interest above the de minimis thresholds. Typically, the emissions reductions
4149 from mitigation measures to demonstrate conformity must occur within the same calendar year
4150 as the emissions subject to conformity. However, some states do allow exceptions to this rule
4151 on a case-by-case basis. The allowances can neither cause nor exacerbate the violation of the
4152 NAAQS nor impede an area's attainment strategy.

4153

4154 Some regulating agencies may approve mitigation measures of different precursors of the same
4155 pollutant. For example, in the case of ozone (O₃) whose precursors are VOCs and NO_x, an
4156 action which reduces VOCs may be approved to offset the action's increase in NO_x emissions.
4157 For approval of these mitigation measures, these trades must be allowable under local
4158 regulations and have a demonstrated environmental benefit.

4159
4160 Some states have also established mandates regarding mitigation. For example, in 1970,
4161 California enacted the California Environmental Quality Act (CEQA) which requires public
4162 agencies to prepare an Environmental Impact Report (EIR) for projects which may adversely
4163 affect the environment. The EIR must identify the adverse effects, propose alternatives, and
4164 describe how those effects can be mitigated. Under CEQA, public agencies are required to
4165 implement feasible mitigation measures, or establish and implement alternatives that would
4166 mitigate significant adverse effects to the environment.

4167
4168 The acceptable methodologies, algorithms, and emission factors for quantifying mitigated and
4169 unmitigated air emissions are described in the latest versions of the AF Mobile, Stationary, and
4170 Transitory Guides. Additionally, the Air Force Air Quality Environmental Impact Analysis
4171 Process (EIAP) Guide serves as the USAF's implementing tool for NEPA and provides the
4172 USAF with a framework on how to comply with NEPA and the President's Council on
4173 Environmental Quality (CEQ). The following pages detail several feasible measures that can
4174 be reasonably expected to reduce air emissions from several pollutant emitting sources.

4175

4176 **12.2 Fugitive Dust (PM₁₀)**

4177 Dust is defined as suspended geologic, organic, synthetic, or dissolved solids and does not
4178 include the particulate matter emitted by internal or external combustion processes. Fugitive
4179 dust includes the particulate matter which cannot reasonably pass through a chimney, stack, or
4180 vent. Emissions of fugitive dust are generated by the forces of wind or machinery acting on
4181 exposed material. Fugitive dust primarily consists of soil, though it may also be emitted from
4182 powdered or aggregate materials deposited on the ground or from vehicle trackout.

4183 Additionally, dust emissions from paved roads include tire and break wear particles.

4184 Activities/sources which may generate fugitive dust include Construction and Demolition,
4185 Materials Handling, Paved Roads, Unpaved Roads, and Storage Piles (SCAQMD 2010).

4186

4187 **12.2.1 Construction and Demolition**

4188 Fugitive dust emissions generated during construction are associated with land clearing,
4189 excavation, drilling, blasting, and cut and fill operations as well as from vehicle traffic at the
4190 construction site. While daily fugitive dust emissions may vary substantially, the total emitted
4191 volume of fugitive dust is "proportional to the area of land being worked and level of

4192 construction activity” (WRAP 2006). There are several dust control methods which may or
4193 may not be feasible for every construction project. Dust suppressant methods include:

- 4194 • **Watering** – Typically readily available and relatively inexpensive, using water as a dust
4195 suppressant does not have any negative environmental impact, though it is effective only
4196 for a short period of time which varies depending on site temperature and humidity.
- 4197 • **Chemical Stabilizers** – include a variety of substances such as:
 - 4198 ○ Water absorbing products (e.g., calcium chloride brine, magnesium chloride brine,
4199 sodium chloride) – suitable for low humidity climates but must be frequently
4200 reapplied in dry climates, are corrosive, and negatively impact water quality and
4201 aquatic life.
 - 4202 ○ Organic petroleum products (e.g., asphalt emulsions, dust oils, petroleum resins) – not
4203 suitable for non-traffic areas and contain polycyclic aromatic hydrocarbons which
4204 are considered HAPs and may result in significant negative environmental impacts.
 - 4205 ○ Organic non-petroleum products (e.g., ligninsulfonates, vegetable oils, oil emulsions)
4206 – effectiveness is negatively impacted (and potentially completely impaired) by rain
4207 while also potentially detrimental to freshwater aquatic life.
 - 4208 ○ Polymer products (e.g., polyvinyl acetates, vinyl acrylics) – non-toxic and non-
4209 corrosive, these products increase the load bearing strength of all soil types and serve
4210 to prevent wind and water erosion.
 - 4211 ○ Synthetic Products (e.g., iso-alkane compounds) – easy to apply and, since these
4212 products utilize environmentally friendly synthetic fluids, they are considered non-
4213 hazardous under OSHA, EPA, and US DOT.
- 4214 • **Sand Fences** – can be used for beautification and erosion control in some areas, this
4215 method is most effective when used in conjunction with chemical stabilizers.
- 4216 • **Perimeter Sprinklers** – generally readily available without negative environmental
4217 impact, these work best when used in conjunction with other measures.
- 4218 • **Tire Cleaning Systems at Site Exit** – this method serves to reduce or prevent trackout
4219 from construction vehicles as they travel from the work site onto paved roads.
- 4220 • **On-Site Speed Control** – commonly used method which reduces the generated fugitive
4221 dust by reducing soil disturbance caused by on-site vehicles.

4222
4223 Calculation of unmitigated emissions under this subcategory utilize site data and those
4224 algorithms found in the construction chapter of this guide as well as the on-road vehicle
4225 chapter of the mobile guide. Specifically, for active demolition and debris removal, refer to
4226 section 4.3.1.1 of this guide and section 4.3.1.2 for all other construction activities. For
4227 guidance on emissions estimates for trackout and traffic on unpaved roads, refer to section
4228 5.2.2 of the Mobile Guide.

4229 If the particulate control efficiency of a mitigation measure is known or may be estimated, it
 4230 may be applied to the uncontrolled emissions to determine the extent of the mitigated dust
 4231 emissions. Examples of mitigation measures to control fugitive dust resulting from
 4232 construction and demolition (with their respective control efficiency) is provided in Table 12-1.

4233 **Table 12-1. Mitigation Measures for Controlling Fugitive Dust from Construction and**
 4234 **Demolition**

Source Activity	Mitigation Measure	PM ₁₀ Control Efficiency	Con
Active demolition and debris removal	Apply water every 4 hours to the area within 100 feet of a structure being demolished	36%	
Trackout	Use a gravel apron, 25 feet long by road width	46%	
Trackout ^a	Install wheel washers at the entrance to construction sites for all exiting trucks	50%	SCAQMD, SIP for PM ₁₀ in pgs. 4-11
Post-demolition stabilization	Apply dust suppressants (e.g., polymer emulsion) to disturbed areas upon completion of demolition	84%	For actively disturbed areas
Demolition Activities	Apply water to disturbed soils after demolition is completed or at the end of each day of cleanup	10%	14-hour watering schedule
Demolition Activities	Prohibit demolition activities when wind speeds exceed 25 mph	98%	Estimated for high wind disturbance activities.
Construction Activities	Apply water at various intervals to disturbed areas within construction site	61%	3.2-hour watering interval
Scraper loading and unloading	Require minimum soil moisture of 12% for earthmoving	69%	AP-42 emission factor equated to increasing soil moisture
Construction traffic	Limit on-site vehicle speeds to 15 mph	57%	Assume linear relationship between uncontrolled vehicle speed
Wind erosion from inactive areas ^a	Apply chemical soil stabilizers on inactive construction areas (disturbed lands within construction projects that are unused for at least four consecutive days)	Up to 80%	Section 13.2.2 - "Unpaved Pollutant Emission Factors and Area Sources, Fifth Edition, California Air Resources Board, California Air Pollution Control Agency, November 2006
Wind erosion from inactive areas ^a	Plant tree windbreaks on the windward perimeter of construction projects if adjacent to open land.	4% (15% for mature trees)	SCAQMD, SIP for PM ₁₀ in pgs. 5-15
Wind erosion from inactive areas ^a	Plant vegetative ground cover in disturbed areas as soon as possible	5% - 99% (based on planting plan)	SCAQMD, SIP for PM ₁₀ in pgs. 5-15

4235 Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation
 4236 measures that address the same source of emissions would not be the sum of both measures).

4237 Source (unless otherwise stated): Countess Environmental, WRAP Fugitive Dust Handbook, September 7, 2006. Table
 4238 provides cited source's original references.

4239 a. Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February
 4240 2008.
 4241

4242 **12.2.2 Materials Handling**

4243 Fugitive dust emissions from materials handling refer to those suspended particulates generated
 4244 during the handling and transfer of materials between processes. These emissions may be
 4245 generated during loading and loadout of material at a storage pile, at transfer points between
 4246 conveyors or vehicles used to haul aggregate, or through disturbances of the material in storage
 4247 piles caused by strong winds. Total fugitive dust emissions from this subcategory are
 4248 dependent upon the characteristics of the storage pile such as its age, moisture content, and
 4249 proportion of aggregate fines. Generally, the older the storage pile, the lower its potential to
 4250 generate fugitive dust. This is partially due to an increased moisture content of the interior of
 4251 the storage pile, either from rain or watering, which slows the drying of the aggregate.

4252
 4253 Worst-case conditions for dust generated through material handling occur under dry, windy
 4254 conditions. Therefore, the principal means for the control of these emissions is with watering
 4255 and chemical wetting agents, though other measures exist. The most common control
 4256 measures for materials handling and their respective control efficiencies are provided in Table
 4257 12-2.

4258 **Table 12-2. Materials Handling Mitigation Measure Control Efficiencies**

Mitigation Measure	PM ₁₀ Control Efficiency	Comments
Continuous water spray at conveyor transfer point	62%	The control efficiency achieved by increasing the moisture content of the material from 1% to 2% is calculated utilizing the AP-42 emission factor equation for materials handling which contains a correction term for moisture content.
Haul trucks shall maintain at least 2'0" of freeboard	90%	Monterey Bay Unified Air Pollution Control District (MBUAPCD)
Cover all trucks hauling dirt, sand, or loose materials	90%	Monterey Bay Unified Air Pollution Control District (MBUAPCD)

4259
 4260 Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation
 4261 measures that address the same source of emissions would not be the sum of both measures).
 4262 Source: Countess Environmental, WRAP Fugitive Dust Handbook, September 7, 2006. Table provides cited source's original
 4263 references.
 4264

4265 If the mean wind speed and moisture content of the material is known or can be estimated, the
 4266 PM₁₀ emissions may be calculated using Equation 12-1.

$$4267 \quad E(Pol) = k \times 0.0032 \times \frac{(U/5)^{1.3}}{(M/2)^{1.4}} \times (1 - CE) \times A$$

4268 **Equation 12-1**

4269

4270

4271 Where,

4272 **E(Pol)** = Annual PM₁₀ or PM_{2.5} emissions (lb/yr)

4273 **K** = Particle size multiplier. **This is 0.35 for PM₁₀ and 0.053 for PM_{2.5}.**

4274 **U** = Mean wind speed (mph)

4275 **M** = Material moisture content (%)

4276 **CE** = Control Efficiency. **0 if unmitigated or taken from Table 12-1.**

4277 **A** = Annual throughput (ton/yr)

4278

4279 12.2.3 Paved Roads

4280 Particulate emissions from paved surfaces consists of the loose material on the road surface
 4281 that is disturbed and resuspended due to the turbulent wake caused from on-road vehicles. The
 4282 volume of emitted particulate is dependent on the loose material present on the road surface, or
 4283 surface loading. Over time, the surface loading should reach an equilibrium in which the
 4284 amount of material resuspended is equal to the amount of material deposited on the road
 4285 surface. However, this equilibrium can be disrupted for a variety of reasons which may
 4286 include the application of granular materials used for snow and ice control, trackout, and
 4287 deposition from erosion of surrounding areas. The equilibrium surface loading values depend
 4288 upon variables such as vehicle mean speed, average daily traffic, number of lanes, and the
 4289 fraction of heavy gross weight vehicles. Typical silt loading values for paved roads at select
 4290 industrial facilities are provided in Table 12-3.

4291 **Table 12-3. Typical Silt-Loading Values for Paved Roads at Industrial Facilities**

Industry	Silt Loading (g/m ²)	
	Range	Mean
Asphalt Batching	76 - 193	120
Concrete Batching	11 - 12	12
Sand and gravel processing	53 - 95	70

4292

4293 SOURCE: Section 13.2.1 - "Paved Roads," *Compilation of Air Pollutant Emission Factors - Volume I: Stationary Point and*
 4294 *Area Sources*, Fifth Edition, U.S. Environmental Protection Agency, January 2011.

4295

4296 Since the volume of emitted dust is a function of the road surface silt loading, the primary
 4297 control techniques to mitigate these emissions involve removal of the material or prevention of
 4298 material deposit. Some examples of material removal include vacuum sweeping, water
 4299 flushing, and broom sweeping or flushing. Preventative examples include paving over
 4300 unpaved lots or work sites or covering truck loads and are generally more cost effective in the
 4301 long term than material removal. A summary of control measures and their respective
 4302 efficiencies is provided in Table 12-4.

4303

Table 12-4. Paved Roads Mitigation Measure Control Volume

Mitigation Measure	Source Component	PM ₁₀ Control Efficiency	Comment
Implement street sweeping program with non-efficient vacuum units (14-day frequency)	Local streets	7%	MRI, September 1992. For non-PM ₁₀ 55% efficient sweeping, 5.5 day equilibrium VMT weighted sweeping frequency (7 to 30)
	Arterial/collector streets	11%	
Implement street sweeping program with PM ₁₀ efficient vacuum units (14-day frequency)	Local streets	16%	MRI, September 1992. For PM ₁₀ efficient sweeping, 8.6 day equilibrium VMT weighted sweeping frequency (7 to 30)
	Arterial/collector streets	26%	
Require streets to be swept by non-efficient vacuum units (once per month frequency)	Local, arterial, and collector streets	4%	MRI, September 1992. For non-PM ₁₀ 55% efficient sweeping, 5.5 day equilibrium VMT weighted sweeping frequency (7 to 30)
Require streets to be swept by PM ₁₀ efficient vacuum units (once per month frequency)	Local, arterial, and collector streets	9%	MRI, September 1992. For PM ₁₀ efficient sweeping, 8.6 day equilibrium VMT weighted sweeping frequency (7 to 30)
Require wind- or water-borne deposition to be cleaned up within 24 hours after discovery	All Streets	100%	Assumes total cleanup of spill on roadway
Install pipe-grid trackout-control device	Mud/dirt carryout	80%	Sierra Research, 2003.
Install gravel bed trackout apron (3 in deep, 25ft long and full road width)	Mud/dirt carryout	46	MRI, April 2001
Require paved interior roads to be 100 foot long and full road width, or add 4 foot shoulder for paved roads	Mud/dirt carryout	42	MRI, April 2001

4304
4305
4306
4307

Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original references.

4308 Section 5.2.2 of the latest version of the Mobile Source Guide provides the algorithms needed
4309 to calculate fugitive emissions from paved road use. Additionally, the guide includes Air
4310 Force-specific emission factors that were calculated using on-road average vehicle weight data.
4311 Refer to that section of the Mobile Guide for specific guidance on calculating the uncontrolled
4312 emissions from paved road use. Mitigated emissions estimates may then be estimated using
4313 this calculated total and the appropriate control method and respective efficiency found in
4314 Table 12-4.

4315

4316 **12.2.4 Unpaved Roads**

4317 As with the travel of vehicles along paved roads, fugitive particulate emissions from unpaved
4318 roads are the result of the suspension of particles from the turbulent wake of on-road vehicles.
4319 However, the volume of fugitive particulate emissions is generally much higher for travel
4320 along unpaved roads with the quantity of dust emissions varying linearly with traffic volume.
4321 The force of the wheels on unpaved surfaces pulverizes surface material while continually
4322 lifting and dropping particulate while the vehicle is in motion. Emissions from unpaved roads
4323 are a function of the surface silt content and increase with increasing average vehicle weight.

4324

4325 Control of emissions from unpaved roads generally fall under one of the following:

- 4326 • Vehicle restrictions
- 4327 • Surface improvements, or
- 4328 • Surface treatments.

4329

4330 Vehicle restrictions reduce dust emissions by lowering the mean vehicle speed or altering the
4331 amount and type of vehicle traffic on the road. Lowering the speed limit reduces the
4332 turbulence created by each vehicle and reduces the volume of resuspended particulate. Road
4333 traffic may be reduced through the implementation of ride sharing or through instituting
4334 bussing programs. While dust emissions increase with the increase in the average vehicle
4335 weight, the reduction in total vehicle miles traveled on the unpaved roads may result in lower
4336 emissions.

4337

4338 Surface improvements work to alter the road surface and are relatively permanent. Paving is
4339 the most obvious improvement, though it is not always feasible at a facility or work site and
4340 can be cost prohibitive. From an environmental standpoint, it is also important to note that
4341 even though a paved surface may improve fugitive dust emissions, a strategy for routine
4342 cleaning should be adopted to reduce silt loading, especially if the paved road is near an
4343 unpaved road or an unpaved work site with heavy traffic.

4344

4345 Surface treatment are temporary solutions that require periodic application. The reapplication
4346 frequency varies with the treatment itself – wet suppression through water application may last
4347 less than an hour in extreme summer conditions while chemical dust suppressants may work

4348 for several weeks. Since wet suppression works through increasing the material moisture
 4349 content, the control efficiency of this measure depends on how quickly the road dries. This
 4350 depends on the amount of water applied; application intervals; number, speed, and average
 4351 gross weight of the vehicles traveling on the surface, and the meteorological conditions.
 4352 Chemical dust suppressants change the physical characteristics of the road surface material to
 4353 form a hardened surface. The control effectiveness of applying chemical dust suppressants
 4354 depend on the chemical concentration; the amount applied; application intervals; number,
 4355 speed, and average gross weight of the vehicles traveling on the surface; and meteorological
 4356 conditions. Table 12-5 provides the control efficiencies for control measures on unpaved roads.

4357 **Table 12-5. Unpaved Roads Mitigation Measure Control Efficiencies**

Mitigation Measure	PM ₁₀ Control Efficiency	Comments
Limit maximum speed on unpaved roads to 25 mph	44%	Assumes linear relationship between PM10 emissions and vehicle speed and an uncontrolled speed of 45 mph
Pave unpaved roads and unpaved parking areas	99%	Based on comparison of paved road and unpaved road PM10 emission factors
Implement watering twice a day for industrial unpaved road	55%	MRI, April 2001
Apply dust suppressant annual to unpaved parking areas	84%	CARB, April 2002

4358
 4359 Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original
 4360 references.
 4361

4362 Section 5.2.2 of the latest version of the Mobile Source Guide provides the algorithms needed
 4363 to calculate fugitive emissions from unpaved road use. Additionally, the guide includes Air
 4364 Force-specific emission factors that were calculated using on-road average vehicle weight data.
 4365 Refer to that section of the Mobile Guide for specific guidance on calculating the uncontrolled
 4366 emissions from unpaved road use. Mitigated emissions estimates may then be estimated using
 4367 this calculated total and the appropriate control method and respective efficiency found in
 4368 Table 12-5.
 4369

4370 **12.2.5 Storage Piles**

4371 Wind erosion may act upon any exposed soils or piles of aggregate material at a facility to
 4372 generate fugitive dust emissions. The extent of the particulate emission rate depends upon the
 4373 erosion potential of the surface material. Aggregate materials or those that have hardened
 4374 surfaces, have a lower erosion potential and experience rapidly decaying particulate emission
 4375 rates during erosion events. Sand and loose soils, however, sustain high particulate emission
 4376 rates due to their high erosion potentials.

4377 Control measures used to reduce the erosion potential of storage piles either include stabilizing
 4378 the surface or through shielding. Surface stabilization is achieved through periodic watering of
 4379 the material while shielding involves either covering the material or enclosing the pile on at
 4380 least three sides. Control efficiencies for these measures are provided in Table 12-6.
 4381

4382 **Table 12-6. Storage Pile Wind Erosion Mitigation Measure Control Efficiencies**

Mitigation Measure	PM ₁₀ Control Efficiency	Comments
Require construction of 3-sided enclosures with 50% porosity	75%	Sierra Research, 2003. Determined through modeling of open area windblown emissions with 50% reduction in wind speed and assuming no emission reduction when winds approach open side
Water the storage pile by hand or apply cover when wind events are declared	90%	Fitz et al., April 2000

4383
4384 Source: Countess Environmental, *WRAP Fugitive Dust Handbook*, September 7, 2006. Table provides cited source's original
4385 references.

4386
4387 Section 13.2.5 of AP-42 describes a procedure for calculating particulate emissions from wind
4388 erosion of storage piles. However, a simpler method is presented here. For active storage
4389 piles, the EPA established the following algorithm for calculating fugitive particulate through
4390 wind erosion:

$$4391 \quad E(\text{Pol}) = k \times \frac{s}{1.5} \times \frac{365 \times (365 - p)}{235} \times \frac{f}{15} \times (1 - CE) \times A$$

4392 **Equation 12-2**

4393 Where,

4394 **E(Pol)** = Annual emissions of PM₁₀ or PM_{2.5} (lb/yr)

4395 **k** = Particle size multiplier. **This is 0.85 for PM₁₀ and 0.13 for PM_{2.5}.**

4396 **s** = Silt content of the material (wt. %)

4397 **p** = Number of days in a year with at least 0.01 inch of precipitation

4398 **f** = Percentage of time unobstructed wind speed exceeds 12 mph at the mean pile
4399 height

4400 **CE** = Control efficiency. **0 if unmitigated or use Table 12-6**

4401 **A** = Total size of surface (acre)

4402

4403 Local climatological data reports from nearby weather stations can provide wind speed and
4404 precipitation data needed for calculations.

4405

4406 **12.3 Heavy-Duty Equipment**

4407 Construction, land clearing, or landfill operation are just a few activities that require the use of
4408 heavy-duty off-road equipment. Heavy duty equipment is generally powered by reciprocating
4409 internal combustion engines operating on gasoline or diesel fuel. In a reciprocating engine, a
4410 piston moves inside a cylinder to compress an air/fuel mixture. The air/fuel mixture combusts
4411 and expands, pushing the piston through the cylinder. The piston returns, pushing out the
4412 exhaust gases, and the cycle is repeated. Emissions generated through this process include
4413 NO_x, CO, VOC, SO_x, PM₁₀, PM_{2.5}, as well as GHGs. The EPA has worked to lower
4414 emissions from heavy duty equipment by imposing emission limits on manufacturers.

4415 However, criteria pollutant emissions from the use of heavy-duty off-road equipment may still
4416 be significant and may only be exacerbated if older equipment is used.

4417
4418 Mitigation of emissions from heavy duty equipment use falls into one of three categories:

- 4419 • Controls on Activity,
- 4420 • Equipment Engine Repowers, or
- 4421 • Equipment Retrofitting

4422
4423 Controls on activity limits emissions through limiting the number of vehicles used, the type of
4424 fuel used, the hours of operation, and the duration of use. The control efficiencies of many of
4425 these measures depend upon the emission rate of the specific piece of equipment used and total
4426 operation time. Table 12-7 provides the control efficiencies for this category of mitigation
4427 measures.

4428 **Table 12-7. Heavy-Duty Activity Limit Mitigation Measure Control Efficiencies**

Mitigation Measure	Control Efficiencies					Comments
	CO	NO _x	VOC	SO _x	PM	
Limit Use of Equipment	Refer to Chapter 4 of the latest version of the Mobile Source Guide					
Replace diesel-powered equipment with gasoline-powered	Refer to Chapter 4 of the latest version of the Mobile Source Guide					
Use PuriNO _x emulsified diesel fuel in existing engines	--	14%	--	--	63%	ARB interim verification of 1/31/01

4429
4430 Note: These effectiveness estimates are not additive within a source category (i.e., the benefit of two or more mitigation
4431 measures that address the same source of emissions would not be the sum of both measures).

4432 Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), *CEQA Air Quality Guidelines*, February 2008

4433 "--" Indicates that no data is available.

4434
4435 Heavy-duty equipment emission rates vary depending on the equipment type and fuel used. To
4436 estimate typical emissions and calculate the potential and extent for mitigated emissions, refer
4437 to chapter 4 Non-road engines of the latest version of the Mobile Guide. The extent of
4438 mitigated emissions of a proposed measure may be determined using the algorithms and
4439 emission factors in that chapter to compare baseline and mitigated emissions. For example, if a
4440 mitigation plan calls for the use of gasoline powered equipment in place of diesel-powered

4441 equipment to lower NO_x, the total emissions of the proposed gasoline-powered equipment may
 4442 be calculated and subtracted from the original diesel-powered equipment emissions to estimate
 4443 the total savings. Equipment engine repower refers to replacing an engine with an updated
 4444 engine with lower emission rates. The control effectiveness is dependent upon the existing
 4445 engine's applicable tier level and the tier level of the replacement engine. While estimates for
 4446 total mitigated emissions may be calculated using manufacturer data for each engine, the
 4447 following tables provide a quick estimate of the emissions reductions that may be reasonably
 4448 expected with engine repowers. Note that this table refers to diesel-powered equipment. For
 4449 repowers of other equipment type, use the emission factors found in chapter 4 of the latest
 4450 version of the Mobile Guide or engine manufacturer data if available.

4451 **Table 12-8. Uncontrolled to Tier 1, 2, 3, and 4 Diesel Engine Repower Emission**
 4452 **Reduction Percentages**

Model Year	Engine Size (hp)	Uncontrolled to Tier 1			Uncontrolled to Tier 2			Uncontrolled to Tier 3			Uncontrolled to Tier 4		
		NO _x	VOC ^a	PM	NO _x	VOC ^a	PM	NO _x	VOC ^a	PM	NO _x ^b	VOC ^a	PM
pre 1988	75 - 99	43%	31%	9%	56%	84%	50%	72%	90%	50%	98%	92%	98%
1988+	75 - 99	15%	0%	0%	35%	76%	40%	59%	85%	40%	96%	88%	97%
pre 1970	100 - 174	47%	48%	45%	64%	85%	60%	78%	91%	60%	98%	91%	97%
1970-71	100 - 174	43%	38%	36%	61%	81%	54%	76%	89%	54%	98%	89%	97%
1972-79	100 - 174	38%	32%	23%	58%	80%	44%	74%	88%	44%	97%	88%	96%
1980-84	100 - 174	33%	27%	23%	54%	78%	44%	72%	87%	44%	97%	88%	96%
1985-87	100 - 174	33%	23%	23%	54%	77%	44%	72%	86%	44%	97%	87%	96%
1987+	100 - 174	9%	0%	0%	39%	70%	20%	63%	82%	20%	96%	83%	95%
pre 1970	175 - 299	47%	34%	28%	64%	84%	73%	78%	90%	73%	98%	91%	97%
1970-71	175 - 299	43%	21%	16%	61%	81%	68%	76%	88%	68%	98%	89%	97%
1972-79	175 - 299	38%	12%	0%	58%	79%	62%	74%	87%	62%	97%	88%	96%
1980-84	175 - 299	33%	7%	0%	54%	77%	62%	72%	86%	62%	97%	87%	96%
1985-87	175 - 299	33%	1%	0%	54%	76%	62%	72%	85%	62%	97%	86%	96%
1987+	175 - 299	9%	0%	0%	39%	70%	45%	63%	82%	45%	96%	83%	95%
pre 1970	300 - 600	47%	34%	25%	65%	84%	72%	78%	90%	72%	98%	91%	97%
1970-71	300 - 600	43%	21%	12%	62%	81%	67%	76%	88%	67%	98%	89%	97%
1972-79	300 - 600	38%	12%	0%	59%	79%	61%	74%	87%	61%	97%	88%	96%
1980-84	300 - 600	33%	7%	0%	55%	78%	61%	72%	86%	61%	97%	87%	96%
1985-87	300 - 600	33%	1%	0%	55%	76%	61%	72%	85%	61%	97%	86%	96%
1987+	300 - 600	9%	0%	0%	40%	71%	45%	63%	82%	45%	96%	83%	95%

4453 Source: SCAQMD, Off-Road Engine Mitigation Measures Table II-C. Calculated values use the average emission rates for
 4454 each model year and engine size calculated by CARB and compared to the EPA emission standards for each tier. In
 4455 instances where the EPA standards are provided for NO_x+NMHC, the source document assumes 95% NO_x and 5% NMHC.

4456 a. Original source lists pollutant as ROG, which is assumed to be equivalent to VOC.

4457 b. Assumes final NO_x emission standards.

4458
4459

4460 **Table 12-9. Tier 1, 2, and 3 to Higher Tier Engine Repower Reduction Percentages**

Engine Size (hp)	Tier 1 to Tier 2			Tier 1 to Tier 3			Tier 1 to Tier 4			Tier 2 to Tier 3			Tier 2 to Tier 4		
	NO _x	VOC ^a	PM	NO _x	VOC ^a	PM	NO _x ^b	VOC ^a	PM	NO _x	VOC ^a	PM	NO _x ^b	VOC ^a	PM
75 - 99	23%	76%	46%	52%	85%	46%	96%	88%	97%	38%	38%	0%	94%	50%	95%
100 - 174	33%	70%	28%	59%	82%	28%	96%	83%	95%	39%	39%	0%	94%	43%	93%
175 - 299	33%	76%	63%	59%	85%	63%	96%	86%	96%	39%	39%	0%	94%	43%	90%
300 - 600	34%	76%	63%	59%	85%	63%	96%	86%	96%	38%	38%	0%	93%	42%	90%

Source: SCAQMD, Off-Road Engine Mitigation Measures Tables II-C, II-D, and II-E. Calculated values use the average emission rates for each model year and engine size calculated by CARB and compared to the EPA emission standards for each tier. In instances where the EPA standards are provided for NO_x+NMHC, the source document assumes 95% NO_x and 5% NMHC.

- a. Original source lists pollutant as ROG, which is assumed to be equivalent to VOC.
b. Assumes final NO_x emission standards.

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Equipment retrofitting involves the installation of emissions-control systems to existing equipment. The most common retrofits include diesel particulate filters (DPF) and diesel oxidation catalysts (DOC). Older equipment that does not already have a DPF or DOC installed will see a reduction in particulate and NO_x emissions after this equipment is added. However, since these systems are designed and sized to an engine's exhaust flow rate, certain systems are compatible with only certain engines. Table 12-10 provides an estimate of the NO_x and PM reductions expected for the installation of these systems on compatible engines. Contact the engine manufacturer to determine compatibility of any DPF and/or DOC prior to adding these measures to a mitigation plan.

4478 **Table 12-10. Heavy-Duty Equipment Retrofit Mitigation Measure Control Efficiencies**

Applicable Engine Model Years; Manufacturers, or Use	Mitigation Measure	Percent Reductions	
		NO _x	PM ₁₀
1993-2002; specific 4-stroke diesel engines - contact manufacturer	Retrofit with DPF from Lubrizol, Cleaire, Donaldson	0-25%	85%
1993-2003; specific 4-stroke diesel engines without EGR - contact manufacturer	Retrofit with an ARB Level 3 verified DPF from ECS-Lubrizol	0%	85%
1993-2002; Caterpillar with PSA bi-fuel system	Retrofit with an ARB Level 3 verified DPF from Clean Air Power	0%	85%
1993-2002; specific 4-stroke diesel engines used as emergency generators - contact manufacturer	Retrofit with an ARB Level 3 verified DPF from Clean Air systems	0%	85%
1991 - 2002; many 4-stroke diesel engines over 150 bhp - contact manufacturer	Retrofit with an ARB level 1 verified DOC from Cleaire, Donaldson, or Lubrizol	0-25%	25%

Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008. DPF = Diesel Particulate Filter. DOC = Diesel Oxidation Catalyst.

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4486 **12.4 Land Use**

4487 On-road vehicles serve as one of the greatest contributors to air pollutants in the world. In
 4488 residential, commercial, and industrial areas where the population density is higher than
 4489 average, the problem with vehicle emissions may be more apparent. To mitigate these
 4490 emissions, a facility should implement transportation demand management measures (TDM)
 4491 which work to reduce or eliminate trips or total vehicle miles traveled (VMT). Mitigation
 4492 measures at commercial, industrial, and institutional worksites may be implemented when
 4493 modification of the employee travel pattern is feasible. This means that the facility can provide
 4494 transportation, implement compressed work schedules, or develop park-and-ride lots that
 4495 accommodate its employees. For residential areas, building pedestrian facilities and bicycle
 4496 paths that connect to an external network to encourage alternatives to vehicle use, though the
 4497 effectiveness of these measures is minimal. Several studies have been conducted to determine
 4498 the effectiveness of land use measures to reduce trips and VMT. Table 12-11 provides an
 4499 estimate of the effectiveness of these measures.

4500 **Table 12-11. Land Use Mitigation Measure Commute Activity Reductions**

Mitigation Measure	Reduction in		Assumptions	Source
	Trips	VMT		
Provide preferential carpool/vanpool parking spaces	0.5%	Same	SOV rate 9 1%, of which 50% is net 9 in trips (assumes shift to 2 person HOV), or 1% x 50% = 0.5%	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
Implement a parking surcharge for single occupant vehicles	2.0%	1.5%	Surcharge of \$3/day/employee SOV	Harvey, Greig, Pricing as a Transportation Control Measure, 1991
Provide for shuttle/mini bus service	2.0%	Same	None	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
Provide bicycle storage/parking facilities and shower/locker facilities.	1.0%	0.5%	Mode share 8 1% (trips 9 1%). Avg. bicycle trip length 50% of avg. work trip length (5 vs. 10 miles), or 1% 9 trips x 50% trip length = 0.5% 9 VMT	U.S. EPA, TCM Information Documents, 1991 and Calif. Energy Commission, Energy-Aware Planning Guide, 1993.
Provide onsite child care centers	N/A	2.0%	7% use daycare, avg. work trip length 10 miles + 5 mile diverted linked trip to child care ctr. Reduces diverted linked trips (33% of VMT), or 7% x 33% 9 VMT . 2% 9 VMT	Calif. Energy Commission, Energy-Aware Planning Guide, 1993 and Association for Commuter Transportation, Case Study Series, 1990.
Provide transit design features within the development	0.05%	0.1%	None	The Planning Center/JHK Assoc., TCM Effectiveness, 1992.
Develop park-and-ride lots	10% per space occupied	89% per space occupied	4 mile avg. to lot, 11% of avg. home-work distance for park-and-riders (35 miles); 10% of VT to lot by bike/walk	Weant and Levinson, Parking, 1990.
Employ a transportation/rideshare coordinator	2.0%	Same	Exposes 25% to ridesharing: of 17% that take part, 50% 9 net trips (assumes SOV shift to 2-person HOV), or 25% x 17% x 50% 9 trips . 2% 9 trips and VMT	Multisystems, Paratransit Options, 1990.
Implement a rideshare program	2.00%	Same	Availability of rideshare material and information 50% as effective as program with rideshare coordinator	See above
Provide incentives to employees to rideshare or take public transportation	1.0%	Same	Subsidies/incentives 9 SOV by 2%, with 50% 9 net trips (assumes SOV shift to 2- person HOV), or 2% trips x 50% 9 trips = 1% trips and VMT	Orski, Kenneth, Can Management of Transportation Demand Work?, 1990.
Implement compressed work schedules	2.0%	Same	9/80 schedule 9 10% of trips, with 20% employee participation per day (staggered days off), or 10% 9 in trips x 20% = 2% trips and VMT	California Energy Commission, Energy-Aware Planning Guide, 1993.
Implement telecommuting program	1.5%	3%	10% of employees 9 15% of trips, or 10% x 15% = 1.5% 9 trips. Avg. trip length for telecommuter 20 miles (200% of 10 mile avg.), or 1.5% 9 trips x 200% = 3% 9 VMT	Cambridge Systematics, TCM Info. Documents, 1991 and Kitamura, et al, Telecommuting & Travel Demand 1990.
Provide bicycle paths within major subdivisions that link to an external	0.1%	Negl.	None	MBUAPCD, 1991 AQMP Appendix A, TCM Measure 9
Provide pedestrian facilities within major subdivisions	0.1%	Negl.	None	MBUAPCD, 1994.

4501 Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008.
 4502 Table provides cited source's original references. SOV = Single-Occupancy Vehicle. HOV = High-Occupancy Vehicle. VMT
 4503 = Vehicle Miles Traveled.
 4504

4505 Guidance for the determination of emissions for on-road vehicle use is provided in chapter 5 of
4506 the latest version of the Mobile Guide. For projects that occur on-base, chapter 5 provides a
4507 simplified procedure that accounts for the typical vehicle mix found at Air Force installations.
4508 However, a more detailed procedure is provided if vehicle mix data is known. The estimated
4509 amount of mitigated emissions may be calculated using the appropriate percent reduction
4510 provided in Table 12-10.

4511

4512 **12.5 Alternative Fuels**

4513 In addition to land use mitigation measures, on-road vehicle emissions may be further reduced
4514 by replacing vehicles that operate on gasoline and diesel fuel with alternative fuels. The most
4515 common alternatives include fully electric, hybrid, methanol, and compressed natural gas
4516 (CNG). The potential reduction in emissions depends on the number of conventional versus
4517 alternative fuel-powered vehicles as well as the total VMT. The estimated emissions
4518 reductions are provided in Table 12-12 by fuel and pollutant. Use the values provided in Table
4519 12-12 and refer to chapter 5 of the latest version of the Mobile Source Guide for guidance on
4520 estimating the potential reduction in emissions using alternative fuels in on-road vehicles.

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Table 12-12. Alternative Fuel Use Emission Reductions

Mitigation Measure (original fuel type)	Emission Reductions vs. Conventional Vehicle						Assumptions	
	CO	NO _x	VOC	PM ₁₀	PM _{2.5}	CO ₂		
Electric Vehicles (gasoline or diesel)	100%	100%	100%	100%	100%	100%	No on-road emissions.	CEQA AIR QUAL Bay Unified Air Po
Ultra Low-Emission Vehicles (gasoline)	50%	64%	82%	50%	50%	50%	None	CEQA AIR QUAL Bay Unified Air Po and The California Regulations, With
Methanol Vehicles (gasoline)	---	64%	71%	---	---	---	85 (85% methanol, 15% gas)	CEQA AIR QUAL Bay Unified Air Po
Liquid Propane Gas Vehicles (gasoline)	90%	64%	71%	90%	90%	25%	LPG vehicles are Low-Emission Vehicles (LEV). NOX, PM, and CO2 emission reductions are same as CNG.	CEQA AIR QUAL Bay Unified Air Po
Compressed Natural Gas Vehicles (gasoline)	90%	35%	50%	90%	90%	25%	None	2021 Air Emission Sources
B20 Diesel Vehicles (diesel)	0%	0%	0%	0%	0%	0%	None	2021 Air Emission Sources

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Note: This table compares running exhaust emission factors for Light-Duty Passenger Vehicles (up to 3,750 lb). Factors do not apply to retrofitted vehicles; these efficiencies will decrease over time.
Source: Monterey Bay Unified Air Pollution Control District (MBUAPCD), CEQA Air Quality Guidelines, February 2008.
Table provides cited source's original references.

4530 **12.6 References**

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4534 Guidelines, February 2008.

4535 SCAQMD 2010, South Coast Air Quality Management District, Off-Road Engines Table II,
4536 May 2010

4537 USEPA 2006a, "Compilation of Air Pollutant Emission Factors -Volume I (AP-42, Volume I),
4538 5th Edition, Chapter 13.2.1, Miscellaneous Sources - Paved Roads," U.S. Environmental
4539 Protection Agency, November 2006

4540 USEPA 2006b, "Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point
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4542 Agency, November 2006

4543 USEPA 2006b, "Compilation of Air Pollutant Emission Factors – Volume I: Stationary Point
4544 and Area Sources (AP-42), Section 13.2.5, "Industrial Wind Erosion," U.S. Environmental
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4549 APPENDIX A – EPA HAP LIST

CAS No.	Chemical/Compound
75070	Acetaldehyde
60355	Acetamine
75058	Acetonitrile
98862	Acetophenone
53963	2-Acetylaminofluorene
107028	Acrolein
79061	Acrylamide
79107	Acrylic Acid
107131	Acrylonitrile
107051	Allyl Chloride
92671	4-Aminobiphenyl
62533	Aniline
90040	o-Anisidine
1332214	Asbestos
71432	Benzene
92875	Benzidine
98077	Benzotrichloride
100447	Benzyl Chloride
92524	Biphenyl
117817	Bis(2-ethylhexyl)phthalate
542881	Bis(chloromethyl)ether
75252	Bromoform
106945	1-Bromopropane
106990	1,3-Butadiene
156627	Calcium Cyanamide
133062	Captan
63252	Carbaryl
75150	Carbon Disulfide
56235	Carbon Tetrachloride
463581	Carbonyl Sulfide
120809	Catechol
133904	Chloramben
57749	Chlordane
7782505	Chlorine
79118	Chloroacetic Acid
532274	2-Chloroacetophenone
108907	Chlorobenzene
510156	Chlorobenzilate
67663	Chloroform
107302	Chloromethyl methyl ether
126998	Chloroprene
1319773	Cresylic Acid
95487	o-Cresol
108394	m-Cresol
106445	p-Cresol
98828	Cumene
94757	2,4-D
3547044	DDE

CAS No.	Chemical/Compound
334883	Diazomethane
132649	Dibenzofurans
96128	1,2-Dibromo-3-chloropropane
84742	Dibutylphthalate
106467	1,4-Dichlorobenzene
91941	3,3-Dichlorobenzidine
111444	Dichloroethyl ether
542756	1,3-Dichloropropene
62737	Dichlorvos
111422	Diethanolamine
121697	N,N-Dimethylaniline
64675	Diethyl Sulfate
119904	3,3-Dimethoxybenzidine
60117	Dimethyl Aminoazobenzene
119937	3,3'-Dimethyl Benzidine
79447	Dimethyl Carbamoyl Chloride
68122	Dimethyl Formamide
57147	1,1-Dimethyl Hydrazine
13113	Dimethyl Phthalate
77781	Dimethyl Sulfate
534521	4,6-Dinitro-o-cresol
51285	2,4-Dinitrophenol
121142	2,4-Dinitrotoluene
123911	1,4-Dioxane
122667	1,2-Diphenylhydrazine
106898	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

CAS No.	Chemical/Compound
7647010	Hydrochloric Acid
7664393	Hydrogen Fluoride
123319	Hydroquinone
78591	Isophorone
58899	Lindane
108316	Maleic Anhydride
67561	Methanol
72435	Methoxychlor
74839	Methyl Bromide
74839	Methyl Chloride
74873	Methyl Chloroform
71556	Methyl Ethyl Ketone
60344	Methyl Hydrazine
74884	Methyl Iodide
108101	Methyl Isobutyl Ketone
624839	Methyl Isocyanate
80626	Methyl Methacrylate
1634044	Methyl tert Butyl Ether
101144	4,4-Methylene bis(2-Chloroaniline)
75092	Methylene Chloride
101688	Methylene Diphenyl Diisocyanate
101779	4,4'-Methylenedianiline
91203	Naphthalene
98953	Nitrobenzene
92933	4-Nitrobiphenyl
100027	4-Nitrophenol
79469	2-Nitropropane
684935	N-Nitroso-N-Methylurea
62759	N-Nitrosodimethylamine
59892	N-Nitrosomorpholine
56382	Parathion
82688	Pentachloronitrobenzene
87865	Pentachlorophenol
108952	Phenol
106503	p-Phenylenediamine
75445	Phosgene
7803512	Phosphine
7723140	Phosphorus
85449	Phthalic Anhydride
1336363	Polychlorinated Biphenyls
1120714	1,3-Propane Sultone
57578	beta-Propiolactone
123386	Propionaldehyde
114261	Propoxur
78875	Propylene Dichloride
75569	Propylene Oxide
75558	1,2-Proplrenimine
91225	Quinoline

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4554 **Appendix A – EPA HAP List (cont.)**

CAS No.	Chemical/Compound
106514	Quinone
100425	Styrene
96093	Styrene Oxide
1746016	2,3,7,8-Tetrachlorodibenzo-p-dioxin
79345	1,1,2,2-Tetrachloroethane
127184	Tetrachloroethylene
7550450	Titanium Tetrachloride
108883	Toluene
95807	2,4-Toluene Diamine
584849	2,4-Toluene Diisocyanate
95534	o-Toluidine
8001352	Toxaphene
120821	1,2,4-Trichlorobenzene
79005	1,1,2-Trichloroethane
79016	Trichloroethylene

CAS No.	Chemical/Compound
95954	2,4,5-Trichlorophenol
88062	2,4,6-Trichlorophenol
121448	Triethylamine
1582098	Trifluralin
540841	2,2,4-Trimethylpentane
108054	Vinyl Acetate
593602	Vinyl Bromide
75014	Vinyl Chloride
75354	Vinylidene Chloride
1330207	Xylenes
95476	o-Xylene
108383	m-Xylene
106423	p-Xylene
---	Antimony Compounds
---	Arsenic Compounds

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

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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-(OCH₂CH₂)_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.