SNAPS Lost Hills Draft Final Report Appendices

A. Website Links

Table A.1 Links to relevant documents and media on SNAPS website.

Title	Website Link
	Homepage, Listerserv, and Overview Videos
SNAPS Program Homepage	https://ww2.arb.ca.gov/our-work/programs/study-neighborhood-air-near-petroleum-sources
SNAPS Listserv (CARB Oil and Gas Listserv)	https://public.govdelivery.com/accounts/CARB/subscriber/new?topic_id=oil-gas
SNAPS Overview Videos	https://ww2.arb.ca.gov/resources/documents/snaps-overview-videos
	Relevant Documents
SNAPS Quality Assurance Project Plan	https://ww2.arb.ca.gov/resources/documents/quality-assurance-project-plan-study-neighborhood-air-near-petroleum-sources
SNAPS Lost Hills Air Monitoring Plan	https://ww2.arb.ca.gov/resources/documents/lost-hills-air-monitoring-plan-snaps
SNAPS Community Selection Process	https://ww2.arb.ca.gov/resources/documents/snaps-community-selection-process
SNAPS First Round Communities	https://ww2.arb.ca.gov/resources/documents/snaps-first-round-communities
SNAPS Fact Sheet	https://ww2.arb.ca.gov/resources/fact-sheets/study-neighborhood-air-near-petroleum-sources
SNAPS Standard Operating Procedures for Monitoring Equipment	https://ww2.arb.ca.gov/resources/documents/study-neighborhood-air-near-petroleum-sources-snaps-monitoring-documents
SNAPS Lost Hills Air Quality Monitoring Demobilization Notice	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-air-quality-monitoring-demobilization-notice
	Community Outreach and Meetings
SNAPS Meeting Schedule	https://ww2.arb.ca.gov/our-work/programs/study-neighborhood-air-near-petroleum-sources/snaps-meeting-schedule

SNAPS Kickoff Meeting - Sacramento Nov 2017	https://ww2.arb.ca.gov/resources/documents/snaps-kickoff-meeting-sacramento-nov-2017
SNAPS Informational Meetings - Jan 2018	https://ww2.arb.ca.gov/resources/documents/snaps-informational-meetings-jan-2018
SNAPS Informational Meetings (Spanish) - Jan 2018	https://ww2.arb.ca.gov/resources/documents/snaps-informational-meetings-spanish-jan-2018
SNAPS Community Selection Process Workshops - Jun/Jul 2018	https://ww2.arb.ca.gov/resources/documents/snaps-community-selection-process-workshops-junjul-2018
SNAPS Community Selection Process Workshops (Spanish) - Jun/Jul 2018	https://ww2.arb.ca.gov/resources/documents/snaps-community-selection-process-workshops-spanish-junjul-2018
SNAPS Lost Hills Community Meeting - Oct 2018	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-community-meeting-oct-2018
SNAPS Lost Hills Community Meeting (Spanish) - Oct 2018	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-community-meeting-spanish-oct-2018
SNAPS Lost Hills Reporting Flyer	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-reporting-flyer
SNAPS Lost Hills Community Gathering and Kickoff Meeting - May 2019	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-community-gathering-and-kickoff-meeting-may-2019
SNAPS Lost Hills Mid-Monitoring Update - October 2019	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-mid-monitoring-update-october-2019
SNAPS Lost Hills Newsletter - May 2020	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-newsletter-may-2020
SNAPS Lost Hills Newsletter – October 2020	https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-newsletter-october-2020
SNAPS Lost Hills Newsletter – February 2021	*https://ww2.arb.ca.gov/resources/documents/snaps-lost-hills-newsletter-february-2021*

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B. Data Overview

a. Data and Data Quality Objectives

Data quality attributes were unique to the instrumentation and methodologies used for analyte sampling, detection, and quantification of air pollutants. A full description of all pollutant data quality objectives can be found in the SNAPS QAPP (link in Appendix A).

Utilizing stationary and mobile monitoring (Section 2.3), SNAPS was able to monitor for over 200 compounds in Lost Hills. These compounds were chosen for SNAPS monitoring after an extensive literature review of potential pollutants across the United States related to oil and gas-related operations (Section 1). These potential oil and gas pollutants were then cross-referenced with available testing methods and quality control procedures, and those that were able to be tested were added to the list of SNAPS monitored pollutants (Table B.1).

Table B.1 SNAPS Data Quality Objectives and Routine QC Checks.

Pollutants	Test	Audit Schedule	Acceptance Criteria for Accuracy/Precision	References
Continuous Measurements				
Ozone	Zero/precision	Bi-weekly	Zero < 5 ppb; precision drift <7.1% of the calibration point	EPA QA Handbook
Hydrogen Sulfide	Zero/precision	Bi-weekly	Zero < 5.1 ppb; precision drift <10.1% of the calibration point	EPA QA Handbook
Methane/Carbon Monoxide/Carbon Dioxide	One-point standard check	Monthly	Methane < 3 ppb; carbon monoxide < 50 ppb; carbon dioxide < 0.5 ppm	Instrument Specifications
VOCs	One-point standard check	Daily	Less than 20% from the calibration point	MLD SOP 066
$PM_{2.5}$	Flow check	Bi-weekly	Less than 4% of the set flowrate check	MLD NLB SOP 055

Black Carbon	Flow check	Bi-weekly	Less than 4% of the set flowrate check	AQSB SOP 400
Discrete Samples				
PAHs	Flow check	Prior and after each sampling period	10% of the set flowrate check	EPA TO-13A
Carbonyls	Flow check	Semi-annual	5% of the set flowrate check	AQSB SOP 801
Glycols				
Metals				
VOCs and Sulfur Containing Compounds	Flow check	Semi-annual	5% of the set flowrate check	AQSB SOP 805

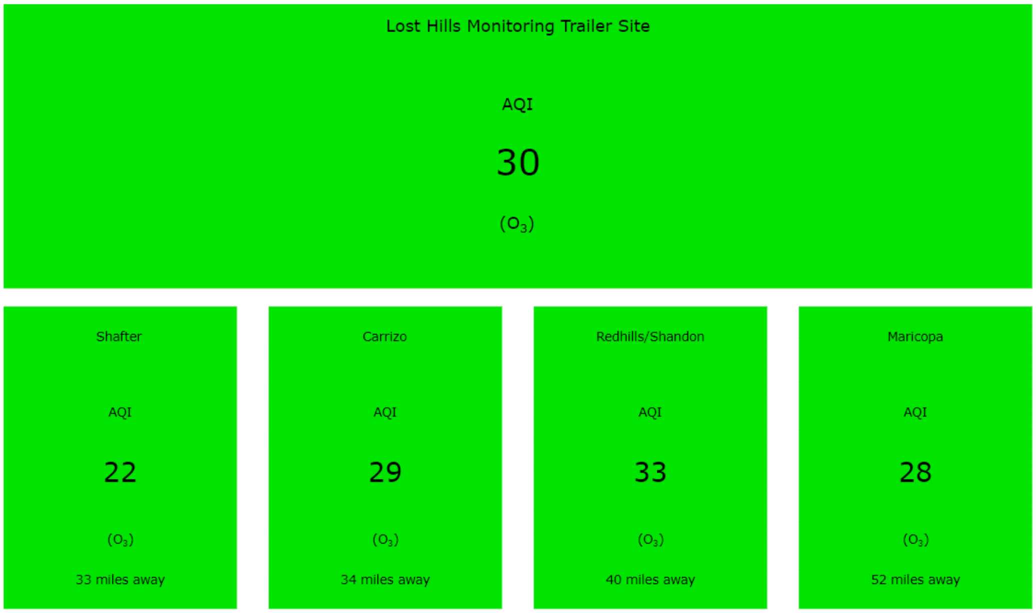
Data were split into two categories: Tier I and Tier II (Table B.2). Tier I compounds were those that could be provided in near real-time to the community and other stakeholders via an online data display on the SNAPS website (Appendix A). Tier II compounds are all other compounds detailed in this report. Both Tier I and Tier II compounds that were measured during SNAPS monitoring in Lost Hills were analyzed (Sections 3-4).

Table B.2 Overview of SNAPS Tier I, Tier II, and mobile monitoring data

Data Tier	On-Site Instrumentation	Discrete Samples	Pollutants	Time to Public Posting of Data
Tier I	X		Methane, Hydrogen Sulfide, Ozone, Carbon Monoxide, $PM_{2.5}$, Black Carbon	Hourly on website and in this report
Tier II	X	X	TACs, non-TAC VOCs, PAHs, glycols, criteria pollutants, and metals (complete list in Appendix D)	This report
Mobile Monitoring	X	As Necessary	Methane, Ethane, Carbon Dioxide, Carbon Monoxide, Hydrogen Sulfide, BTEX	This report

b. Tier I Data

Tier I data consisted of a set of six pollutants measured on-site at the SNAPS trailer. At the request of community members, near real-time data for ozone, $PM_{2.5}$, hydrogen sulfide, carbon monoxide, methane, and black carbon were uploaded within a few hours of data collection on the SNAPS website (Appendix A). The current air quality index, or AQI, in Lost Hills was displayed in relation to other monitoring stations in the region (Figure B.1).



Lost Hills Monitoring Trailer Site

AQI

30

(O_3)

Shafter

AQI

22

(O_3)

33 miles away

Carrizo

AQI

29

(O_3)

34 miles away

Redhills/Shandon

AQI

33

(O_3)

40 miles away

Maricopa

AQI

28

(O_3)

52 miles away

Figure B.1 Screenshot from April 10, 2020, of a portion of the SNAPS data display. The AQI in Lost Hills is displayed in relation to other monitoring sites in the region.

Below the AQI information, key pollutant concentrations were shown relative to ambient air quality standards or reference exposure levels, where applicable. The past week of hourly concentrations of the six pollutants were also displayed in an interactive format, in which the user could zoom in on periods of interest. At the bottom of the data display, the past day and week of wind speeds and directions were displayed to highlight relevant meteorological information.

c. Tier II Data

Tier II data consisted of all data beyond Tier I compounds that were monitored under the SNAPS program through on-site instrumentation and discrete samples. Depending on the pollutant, Tier II compounds were measured hourly with on-site instrumentation, or they were monitored as discrete samples every six or 12 days. Compounds and analysis methods are listed in Table 2.2, including PAHs, aldehydes, glycols, metals, VOCs, and sulfur-containing gaseous compounds.

d. Diesel PM Estimation from BC Measurements

Staff estimated Diesel PM concentrations using BC measurements from the SNAPS trailer. Assuming all emission sources and categories (on-road, off-road mobile, area sources, stationary sources), staff used different methods for different source categories and sectors. After estimating Diesel PM from all emission source categories and sectors, concentrations were then aggregated into 2 km x 2 km or 4 km x 4 km gridded cells for State Implementation Plans (SIPs) and toxic health risk assessment purposes.

e. Potential Uncertainty Surrounding Acrolein Measurements

While there were some notable noncancer health risks associated with acrolein concentrations measured in Lost Hills (Sections 3 and 4 of report), it is important to note that there are several uncertainties associated with analyzing ambient acrolein. First, acrolein can be elevated in "clean" canisters which will result in a measurement that is biased high. Second, the variability of acrolein gas standards used at different labs also results in varying degrees of inaccuracy or bias.[1]

Therefore, it is important to use caution when directly comparing acrolein concentrations, particularly when the collection and analytical methods may differ between data sets. Note that OEHHA compared SNAPS measurements to iADAM data, which are collected in a similar manner (Xontech 910A or ATEC 3454 collection samplers into stainless steel canisters) and analyzed by the same MLD-066 method at the same laboratory.

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[1] U.S. EPA. 2010. Data Quality Evaluation Guidelines for Ambient Air Acrolein Measurements. https://www3.epa.gov/ttnamti1/files/ambient/airtox/20101217acroleindataqualityeval.pdf.

f. Table of Compounds Monitored for in Lost Hills

Table B.3 *List of compounds monitored for in Lost Hills (left-hand column). The corresponding reporting limit is denoted in the same row as the listed compound and corresponding monitoring method used is listed in the same column as the reporting limit. For monitoring methods, those that were measured discretely are listed in blue (first 7 of 13 listed methods from left to right) and those measured continuously on-site are listed in green (last 6 of 13 listed methods from left to right).*

Compound name	**MLD058+MLD066 (µg/m3)**	**TO-13 SIM mode (µg/m3)**	**TO-13 Scan mode (µg/m3)**	**XRF (ng/m3)**	**NIOSH5523 (µg/m3)**	**MLD022 (µg/m3)**	**ASTM D5504 (µg/m3)**	***PAMS (µg/m3)***	***Beta-ray Attenuation (µg/m3)***	***Light Absorption (µg/m3)***	***CRDS (ppb)***	***UV Fluorescence (µg/m3)***	***UV Absorption (ppb)***
1, 3-Dichlorobenzene			0.029										
1,1,1-Trichloroethane	0.055												
1,2,3-trimethylbenzene								0.095					
1,2,4-Trichlorobenzene			0.029										
1,2,4-trimethylbenzene								0.070					
1,2-Dichlorobenzene			0.029										
1,3,5-Trimethylbenzene								0.046					
1,3-Butadiene	0.088												
1,3-Butylene glycol					13.2								
1,4-Dichlorobenzene			0.029										

1-Butene								0.025					
1-Hexene								0.077					
1-Pentene								0.054					
2,2,4-trimethylpentane								0.103					
2,2-dimethylbutane								0.052					
2,3,4-trimethylpentane								0.087					
2,3-dimethylbutane								0.063					
2,3-dimethylpentane								0.075					
2,4,5-Trichlorophenol			0.029										
2,4,6-Tribromophenol			0.150										
2,4,6-Trichlorophenol			0.150										
2,4-Dichlorophenol			0.029										
2,4-dimethylpentane								0.061					
2,4-Dimethylphenol			0.029										
2,4-Dinitrophenol			0.150										
2,4-Dinitrotoluene			0.029										
2,5-Dimethylthiophene							23.0						
2,6-Dinitrotoluene			0.029										
2-Chloronaphthalene			0.029										
2-Chlorophenol			0.029										
2-Ethylthiophene							22.9						
2-Ethyltoluene (or o-Ethyltoluene)								0.054					
2-Fluorobiphenyl (Surr)			0.150										
2-Fluorophenol			0.150										
2-methylheptane								0.040					
2-methylhexane								0.074					
2-Methylnaphthalene		0.0029	0.029										

2-methylpentane (isohexane)								0.026					
2-Methylphenol			0.029										
2-Nitroaniline			0.029										
2-Nitrophenol			0.150										
3 & 4 Methylphenol			0.150										
3,3'-Dichlorobenzidine			0.029										
3-Ethyltoluene (or m-Ethyltoluene)								0.046					
3-methylheptane								0.040					
3-methylhexane								0.074					
3-methylpentane								0.103					
3-Methylthiophene							20.1						
3-Nitroaniline			0.029										
4,6-Dinitro-2-methylphenol			0.150										
4-Bromophenyl phenyl ether			0.029										
4-Chloro-3-methylphenol			0.150										
4-Chloroaniline			0.029										
4-Chlorophenyl phenyl ether			0.029										
4-Ethyltoluene (or p-Ethyltoluene)								0.069					
4-Nitroaniline			0.150										
4-Nitrophenol			0.150										
Acenaphthene		0.0015	0.029										
Acenaphthylene		0.0015	0.029										
Acetaldehyde						0.15							
Acetone	2.370												
Acetonitrile	0.500												
Acetylene (or ethyne)								0.040					

Acrolein	0.690												
Acrylonitrile	0.650												
Aluminum				7.44									
Anthracene		0.0015	0.029										
Antimony Compounds				8.83									
Arsenic				0.56									
Barium				8.83									
Benzene	0.160							0.035					
Benzo[a]anthracene		0.0015	0.029										
Benzo[a]pyrene		0.0015	0.029										
Benzo[b]fluoranthene		0.0015	0.029										
Benzo[g.h,i]perylene		0.0015	0.029										
Benzo[k]fluoranthene		0.0015	0.029										
Benzoic acid			0.150										
Benzyl alcohol			0.029										
Bis (2-chloroisopropyl) ether			0.029										
Bis(2-chloroethoxy)methane			0.029										
Bis(2-chloroethyl)ether			0.029										
Bis(2-ethylhexyl) phthalate			0.029										
Black Carbon										0.01			
Bromine				0.56									
Bromomethane	0.120												
Butane (or n-Butane)								0.067					
Butyl benzyl phthalate			0.029										
Calcium				2.79									
Carbon Disulfide							7.8						
Carbon monoxide											0.04		
Carbon tetrachloride	0.130												

Carbonyl Sulfide							12.3						
Chlorine				2.79									
Chloroform	0.100												
Chromium				1.12									
Chrvsene		0.0015	0.029										
cis-1,3-Dichloropropene	0.450												
Cis-2-butene								0.057					
cis-2-pentene								0.145					
Cobalt				1.12									
Copper				1.67									
Cumene (or Isopropylbenzene)								0.046					
Cyclohexane								0.101					
Cyclopentane								0.042					
Decane (n-Decane)								0.064					
Dibenz[a,h]anthracene		0.0015	0.029										
Dibenzofuran			0.029										
Dichloromethane	0.350												
Diethyl Disulfide							12.5						
Diethyl Sulfide							18.5						
Diethylbenzene - M (m-Diethylbenzene)								0.285					
Diethylbenzene - P (p-Diethylbenzene)								0.461					
Diethylene glycol					13.9								
Diethylphthalate			0.029										
Dimethyl Disulfide							9.7						
Dimethyl phthalate			0.029										
Dimethyl Sulfide							6.4						

Di-n-butyl phthalate			0.058										
Di-n-octyl phthalate			0.029										
Dodecane (or n-Dodecane)								1.021					
Ethane								0.096					
Ethanol	0.940												
Ethyl Methyl Sulfide							15.6						
Ethyl Mercaptan							12.7						
Ethylbenzene	0.870							0.035					
Ethylene (or Ethene)								0.076					
Ethylene glycol (or 1,2-ethanediol)					13.0								
Fluoranthene		0.0015	0.029										
Fluorene		0.0015	0.029										
Formaldehyde						0.078							
Freon 11	0.056												
Freon 113	0.150												
Freon 12	0.100												
Heptane (or n-Heptane)								0.076					
Hexachloro-1,3-cyclopentadiene			0.150										
Hexachlorobenzene			0.029										
Hexachlorobutadiene			0.029										
Hexachloroethane			0.029										
Hexane (or n-Hexane)								0.040					
Hydrogen Sulfide							7.0					2.93	
Iron				1.67									
Isobutane (or 2-Methylpropane)								0.088					

Isopentane (or 2-Methylbutane)								0.088					
Isoprene (or 2-methyl-1,3-butadiene)								0.039					
Lead				1.12									
Indeno[1, 2,3-cd]pyrene		0.0015	0.029										
Isobutyl Mercaptan							18.5						
Isophorone			0.029										
Isopropyl Mercaptan							15.6						
Manganese				1.12									
Mercury				1.12									
Methane											0.025		
Methyl Ethyl Ketone, MEK (or 2-Butanone)						0.42							
Methyl Mercaptan							9.9						
Methylcyclohexane								0.044					
Methylcyclopentane								0.031					
Molybdenum				2.79									
Naphthalene		0.0029	0.029										
n-Butyl Mercaptan							18.5						
Nickel				1.67									
Nitrobenzene			0.029										
N-Nitrosodimethylamine			0.029										
N-Nitrosodi-n-propylamine			0.029										
N-Nitrosodiphenylamine			0.029										
Nonane (or n-Nonane)								0.070					
n-Propyl Mercaptan							15.6						
Octane (or n-Octane)								0.093					

Ozone													3.4
Pentachlorophenol			0.150										
Pentane (or n-Pentane)								0.029					
Perchloroethylene	0.070												
Phenanthrene		0.0015	0.029										
Phenol			0.029										
Phosphorus				1.67									
PM2.5									2.6				
Potassium				3.35									
Propane								0.099					
Propylbenzene								0.052					
Propylene (or Propene)								0.045					
Propylene glycol					13.1								
Pyrene		0.0015	0.029										
Rubidium				0.56									
Selenium				0.56									
Silicon				2.79									
Strontium				1.12									
Styrene	0.430							0.051					
Sulfur				2.23									
tert-Butyl Mercaptan							18.5						
Tetraethylene glycol					14.2								
Tetrahydrothiophene							18.1						
Thiophene							17.2						
Tin				8.87									
Titanium				1.67									
Toluene	0.750							0.058					
trans-1,3-Dichloropropene	0.029												

Trans-2-butene								0.041					
Trans-2-pentene								0.025					
Trichloroethylene	0.110												
Triethylene glycol					13.7								
Undecane (or n-Undecane)								0.409					
Vanadium				1.12									
Vinyl chloride	0.050												
Xylene (o)	0.430							0.035					
Xylenes (m & p)	0.870							0.056					
Yttrium				1.12									
Zinc				0.56									

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C. Source Apportionment Report

a. Source Apportionment Report Executive Summary

Background: The Study of Neighborhood Air near Petroleum Sources (SNAPS)[1] is a program developed by the California Air Resources Board (CARB) and the California Office of Environmental Health Hazard Assessment (OEHHA) in 2017 that includes limited-term, intensive ambient air quality monitoring with a particular focus on characterizing air quality in communities near oil- and gas-related (O&G) operations. Lost Hills, California (CA) was the first community selected under this program. The ambient air monitoring efforts at Lost Hills lasted from May 2019 to April 2020 and included measurements of volatile organic compounds (VOCs) like alkanes, alkenes, and aromatic compounds like benzene, toluene, ethylbenzene, and xylene (BTEX); criteria air pollutants like fine particulate matter ($PM_{2.5}$); and other health affecting air pollutants like black carbon (BC). The purpose of this report is to summarize the quarterly source apportionment analysis of the SNAPS ambient air monitoring data collected at Lost Hills, CA to inform the program managers and key stakeholders (e.g. community) about the source categories that affect the state of air quality in Lost Hills.

Methods: The meteorological data, the ambient air monitoring data, and the meta-data were studied in tandem through statistical analysis to determine the probable direction in which the air pollutants originated from; the diurnal pattern of ambient air pollution levels; and other information that helps associate potential source categories to the measurements made at the SNAPS ambient air monitoring site (also referred to as a receptor site).

The U.S. Environmental Protection Agency (EPA) Positive Matrix Factorization (PMF) model version 5.0 was used for the source apportionment analysis of BC, carbon monoxide (CO), and VOCs for each quarter of the monitoring period. The protocol provided in the PMF User Guide was used in addition to quality assessment and quality control (QAQC) measures and a model performance evaluation strategy developed by the authors. Peer-reviewed literature and the U.S. EPA SPECIATE database were used to support the assignment of PMF results to key source categories.

Conclusion: Quarterly source apportionment analysis suggested that O&G operations can be responsible for 6 – 9% of BC, 39 – 55% of BTEX, and 83 – 94% of total VOC, while mobile sources can be responsible for 91 – 93% of BC, 44 – 61% of BTEX, and 6 – 17% of total VOC. Chemical signatures that represent other potential anthropogenic sources located near the

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[1] https://ww2.arb.ca.gov/our-work/programs/study-neighborhood-air-near-petroleum-sources

receptor site (e.g. commercial, residential, and agricultural) were not resolved by the PMF. Note that these results do not constitute 100% accuracy due to inherent uncertainties in the PMF analysis. The potential co-location and natural mixing of various air pollutant emissions increase the chances of PMF producing chemical profiles that represent mixed source contributions. Therefore, the information presented in this report should be used with caution, and all caveats should be considered prior to further interpretation of the results.

b. Observations at Lost Hills, CA

CARB-MLD sited the SNAPS ambient air monitoring equipment at the Lost Hills Department of Water Resources (DWR) office (35.615746, -119.697231; Figure C.1) from May 2019 to April 2020. This receptor site was located on the western edge of Lost Hills, CA just south of CA State Route 46 (SR 46). There is a small number of permanent housing, trailer parks, and agricultural fields located to the north of the receptor site. A larger cluster of the community is located immediately toward the east. Agricultural land occupies the space between the community and the commercial complexes located within 3 miles east of the receptor site. The commercial complexes are located just west of Interstate 5 (I-5) on/off-ramp and are comprised of multiple truck stops, restaurants, and an RV park.

This receptor site was also less than a mile east of the Lost Hills Oil Field, which produced 9.7 million barrels of oil and 5.2 billion cubic feet of natural gas in 2018.[2] This oil field is the 6th and the 4th largest oil and natural gas producer in California, respectively. Lost Hills Oil Field houses intermediate gas-processing infrastructures as well as abandoned and active wells. The oil field is also subject to periodic drilling and flaring activities. The closest gas-processing plant (Cahn 3 Gas Plant; Chevron) is located approximately 1 mile southwest of the receptor site.

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[2] https://www.conservation.ca.gov/calgem/Online_Data/Pages/WellSTAR-Data-Dashboard.aspx.

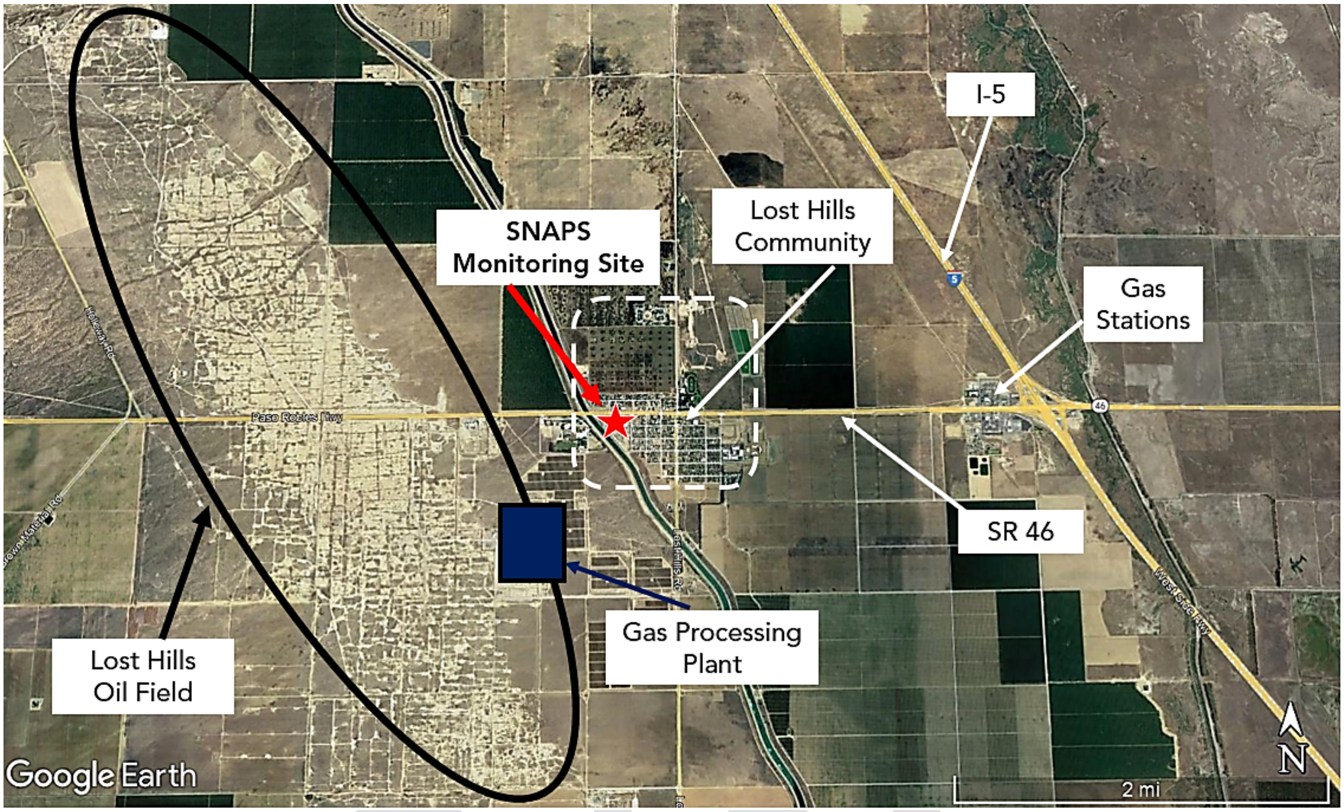

Figure C.1 Map of the greater Lost Hills area showing the locations of the town of Lost Hills (white dashed line), the monitoring site (red star), and various potential sources of air pollution, including the Lost Hills Oil Field (black circle), the gas processing plant (blue rectangle), gas stations, and SR 46 highway and I-5 freeway.

If all sources are sited equally, those with higher emission rates will have a greater influence on the air quality at the receptor site. Since air pollutants can be altered chemically and physically through complex atmospheric processes such as photochemical oxidation (i.e. chemical reactions) and atmospheric turbulence (i.e. motion of air), a significant amount of directly emitted air pollutants can be lost in the atmosphere over time. Therefore, sources located farther away from the receptor site will generally have smaller contributions to the ambient air measurements and add greater uncertainty in the subsequent analysis of the data. This can also affect directly emitted air pollutants classified as hazardous air pollutants (HAPs) and toxic air contaminants (TAC).

c. Source Activities

i. Mobile Sources

SR 46, I-5, and District 6 (South Central Valley) traffic data were extrapolated from the Caltrans PeMS database[3] to understand the typical diurnal traffic activities near Lost Hills, CA. The data were subdivided into quarters defined as **2019 Q3** or 5/20/2019 – 9/30/2019; **2019 Q4** or 10/1/2019 – 12/31/2019; and **2020 Q1** or 1/1/2020 – 3/6/2020. Data collected after March 6th, 2020 were excluded from all subsequent analyses to avoid abrupt changes in source activities associated with the COVID-19 pandemic (see Appendix Section h.i for additional justifications).

The quarterly averaged diurnal passenger car (PC) vehicle-miles-traveled (VMT) patterns were unimodal, with traffic activities that gradually increased in the morning and gradually decreased in the afternoon (Figure C.2). The diurnal PC VMT patterns observed on SR 46 and I-5 near Lost Hills diverged away from the general trends observed in District 6 where cities like Fresno and Bakersfield are also represented. The diurnal PC VMT patterns in District 6 were bimodal with peaks during morning rush hours (6 – 9 AM) and peaks during afternoon rush hours (2 – 5 PM). In all cases, PC activities increased rapidly starting ~3 AM and decreased rapidly starting ~5 PM. Although community-specific traffic data were not obtained during the study period, these differences suggest that Lost Hills does not necessarily experience daily traffic patterns typical of larger and more densely populated urban centers.

The quarterly averaged diurnal truck VMT patterns on SR 46 were also unimodal with no distinct peak during the day. District 6 and I-5 diurnal truck VMT patterns had relatively more pronounced activities in the afternoon (12 – 6 PM) than during early morning hours (Figure C.2B). Similar to PCs, truck activities increased rapidly starting ~2 – 3 AM. Compared to PCs, elevated Truck activities lasted for a relatively longer period on SR 46.

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[3] http://pems.dot.ca.gov/

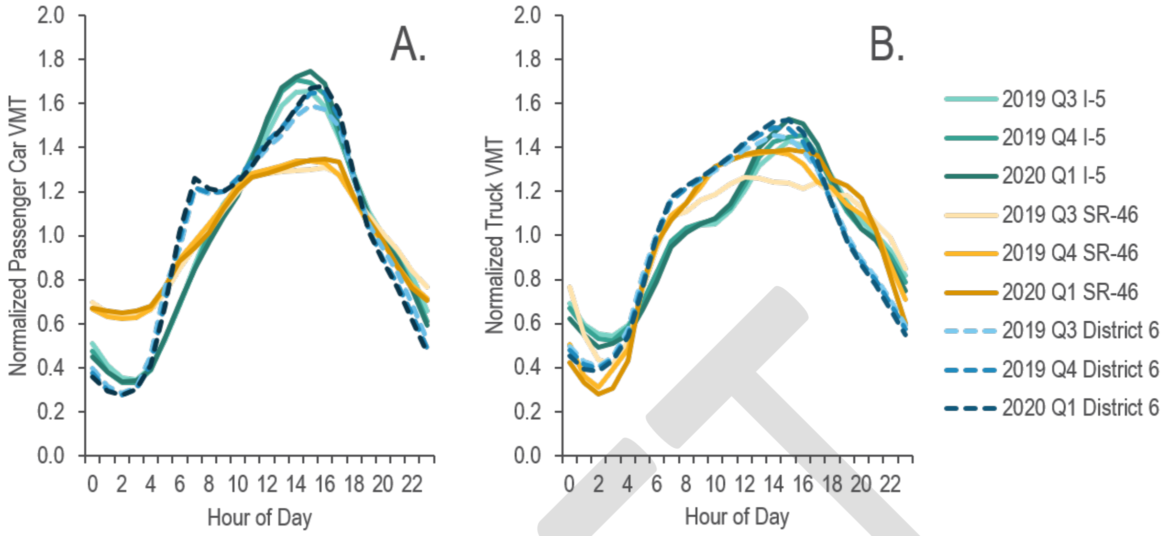

Figure C.2 Quarterly averaged diurnal VMT for (A) PC and (B) trucks at nearby I-5 station, SR 46 station, and District 6. District 6 aggregates VMT data from the South Central Valley defined by Caltrans.

The quarterly weekday-to-weekend VMT ratios on SR 46 ranged from 0.95 to 1.07 for PC and 0.35 to 0.94 for trucks. There were no discernable differences between the diurnal PC and truck VMT patterns for the weekday and weekend on SR 46. The quarterly weekday-to-weekend VMT ratios for I-5 ranged from 0.8 to 0.89 for PC and 1.23 to 1.34 for trucks. Although PC and truck activities exhibited opposite behaviors, both observed a more pronounced VMT peak that began around 10 AM and receded by 8 PM. The quarterly weekday-to-weekend VMT ratios for District 6 ranged from 1.06 to 1.13 for PC and 1.38 to 1.45 for trucks. Similar to I-5, District 6 observed increasing weekend activities by trucks but on the contrary, experienced increasing PC activities. District 6 observed a pronounced PC and truck VMT increase at approximately 8 AM and 4 PM during the weekdays, which aligned well with the expected human activity patterns. These rush-hour VMT peaks in District 6 were not observed during the weekends for PCs nor trucks. The greater traffic volume is an indicator of increased emissions from the transportation sector. The performance of the traffic sensors was variable throughout the study period and caveat should be made when interpreting this information.

ii. O&G Operations

Lost Hills Oil Field operators provided activity data associated with O&G operations near Lost Hills prior to completion of this report (Figure C.3). Although incomplete, the data provided a general understanding of various activities that occurred within the oil field between April 2019 and April 2020.

Drilling and well stimulation activities were most prominent during the summer of 2019, which included a combination of techniques such as water and cyclic steam injection. These activities are associated with various chemicals used and released on-site, with a fraction of the chemical compounds characterized as climate-affecting pollutants or hazardous to health if exposed. More information on air pollutant emissions from O&G operations can be found in CARB's GHG inventory methodology and California Emission Inventory Development and Reporting System (CEIDARS) database.[4,5]

Flaring activities were more prominent during late 2019 and early 2020. Although natural gas flaring can occur as part of drilling operations, flaring can also occur as part of a safety protocol to balance production, processing, transport, storage, and consumption of natural gas during high-demand seasons. Additional information from the oil field operators can help refine the source apportionment analysis.

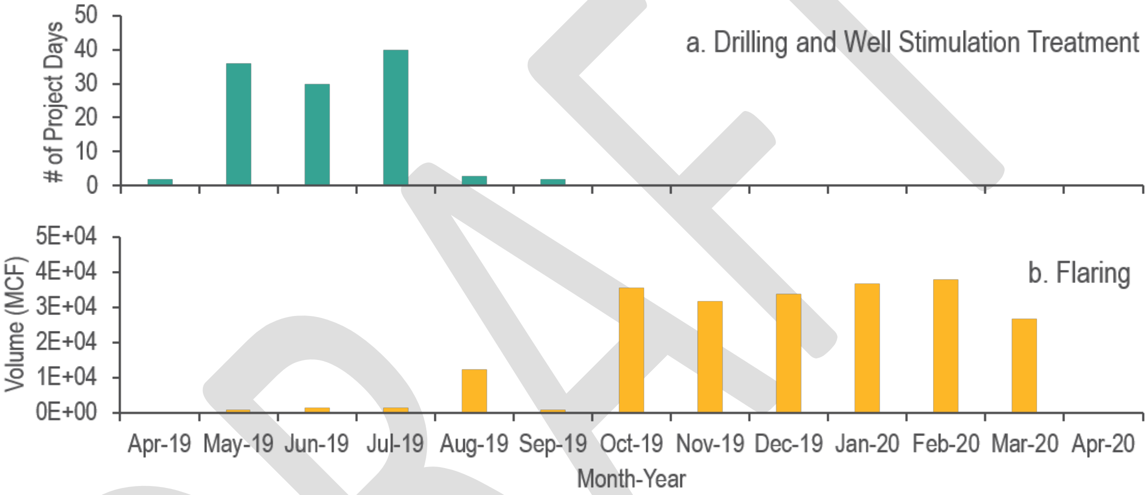

Figure C.3 Lost Hills Oil Field activity data between April 2019 and April 2020. Data presented here are information gathered from two of the oil field operators and may not represent the complete activity log.

Production of O&G on the Lost Hills Oil Field was relatively consistent throughout the study (Figure C.4). Monthly oil production averaged 774,000 [741,509 – 800,021] barrels of oil (bbl) with a standard deviation of only 2.5%.[2] Monthly gas production averaged 404,940 [383,045 – 422,363] million cubic feet (MCF) with a standard deviation of only 2.8%.[2] Data presented in Figure C.4 demonstrate that air pollutant emissions or leaks associated with oil production and gas-processing plant located just southwest of the community, if any, may be consistent

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[4] https://ww2.arb.ca.gov/ghg-inventory-data

[5] https://ww3.arb.ca.gov/ei/drei/maintain/dbstruct.htm

throughout the year unless there were notable changes in the facility/infrastructure operations or venting events that occurred during the study period.

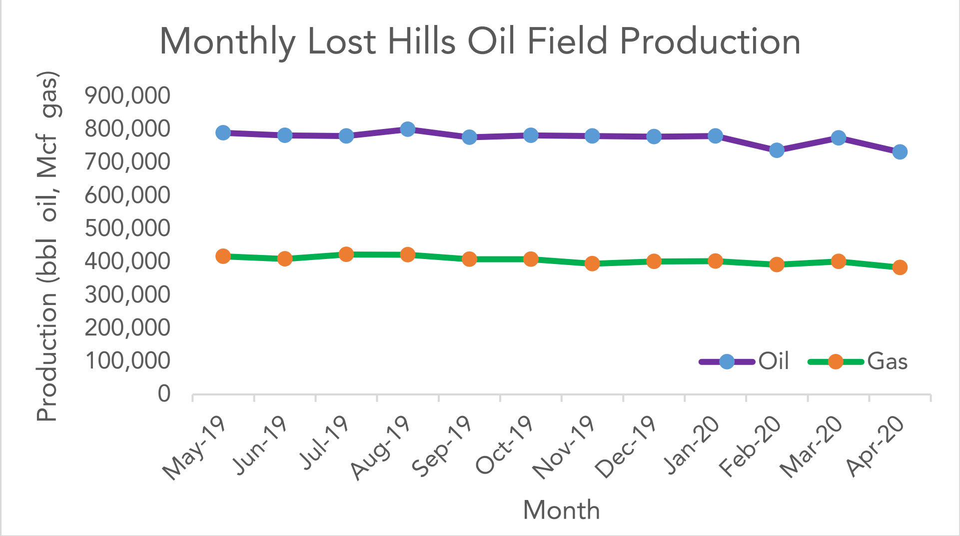

*Figure C.4 O&G production between May 2019 and April 2020 on the Lost Hills Oil Field***Error! Bookmark not defined.**.

iii. Commercial, Residential, and Agricultural Sources

Commercial activities were expected to remain relatively consistent throughout the year, but residential emission sources such as in-home natural gas usage and biomass burning may have influenced the local air quality more prominently during certain parts of the year. Agricultural activities were also expected to follow seasonal crop cycles with periodic controlled burning to manage agricultural fields and to improve plant health. The source apportionment analyses are typically limited by the list of chemical compounds that are measured at a receptor site; understanding of source-level activities data; and accurate characterization of the emissions. Although the emissions from commercial, residential, and agricultural sources probably influenced the air quality at Lost Hills, activities of these relatively inconsistent sources were not gathered during the study period, and therefore the source apportionment analysis was unable to evaluate these source categories effectively. A broader perspective on local sources should be used to caveat the information derived from the source apportionment analysis.

d. Meteorology

2019 Q3 experienced the highest average diurnal wind speeds that generally peaked at ~5 PM. 2019 Q3 was also the only quarter in which the wind speed varied significantly throughout the day [1.1 – 2.0 meters-per-second (m/s) or 2.5 – 6.5 miles-per-hour (mph)] and was consistently greater during the evening hours relative to mid-day conditions. 2019 Q4 and 2020 Q1 experienced mild variation in wind speed throughout the day ranging between

0.8 to 1.6 m/s (or 1.8 to 3.6 mph) on average. All quarters experienced sudden changes in wind direction during early mornings (7 – 9 AM) and sunset hours (5 – 7 PM). This is a phenomenon of the San Joaquin Valley's unique topographical influences on wind patterns. Northerly winds occurred primarily during the daytime, and southerly to westerly winds generally occurred during the nighttime (Figure C.5). Therefore, it was expected that air pollutants from the north (e.g. mix of traffic, residential, and agricultural emissions) and generally to the west (e.g. O&G emissions) would influence the air quality at the receptor site during daytime and nighttime, respectively. Northeasterly to easterly winds were significantly less frequent and were rarely dominant at Lost Hills, suggesting that parts of commercial, residential, and agricultural activities, as well as I-5 traffic emissions, are less likely to drive the overall air quality at the receptor site.

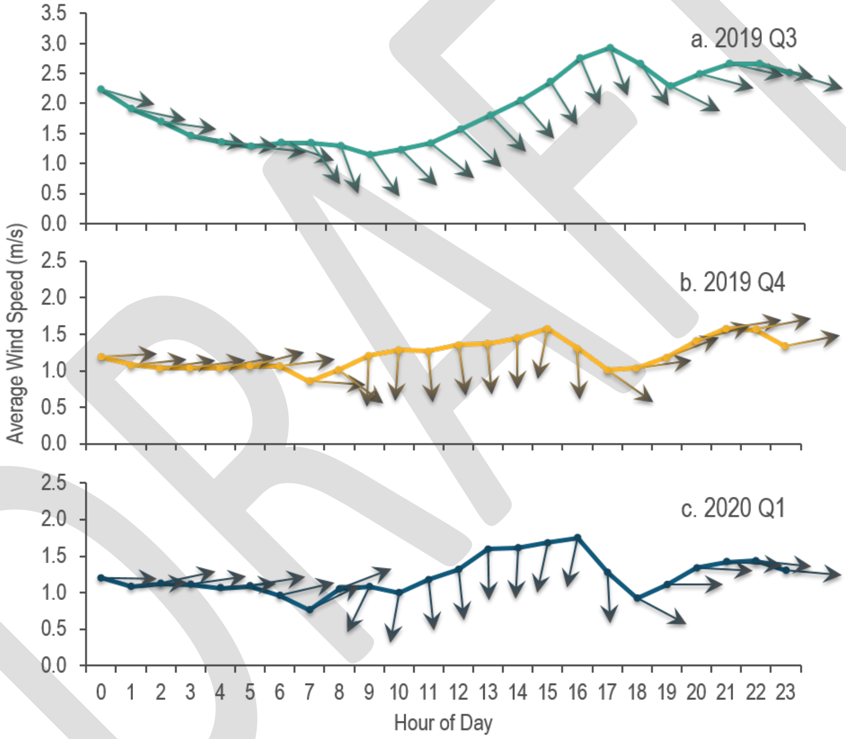

Figure C.5 Average diurnal wind speeds (m/s) and ensemble wind directions for three quarters during SNAPS ambient air monitoring. The arrows indicate ensemble wind directions each hour.

In addition to the wind speed and the wind direction, atmospheric turbulence (i.e. motion of air) has significant influences on the local and regional air quality. High levels of turbulence result in greater dispersion of air pollutant emissions, thus lowering their influences on downwind air quality. In general, atmospheric mixing conditions are greater during the daytime and lesser during evening hours. If other factors remain unchanged, the effects of a nearby source are greatest at night.

Wind speeds and the ensemble wind directions in Figure C.5 represent the averaged meteorological trends for each of the three quarters. Note that hourly meteorology can be significantly more variable compared to the ensemble results. The source apportionment analysis utilized both the generalized meteorological patterns and more detailed hourly information to evaluate the plausible direction in which the air pollutants originated. Information on Conditional Probability Function (CPF) analyses is presented in Appendix Section h.ii.3 and h.iii.

e. Ambient Air Monitoring Data

i. Background Information on BC and VOCs

BC, commonly referred to as soot, enters the atmosphere by combustion of fuels (e.g. internal engine combustions, wildfires, residential burning). BC is the dominant light absorber in aerosol particles. A recent assessment suggests that BC is the second most important climate warming agent in the atmosphere, after carbon dioxide.[6] Besides its climate effect, BC particles are associated with cardiopulmonary morbidity and mortality.[7] Reducing atmospheric BC concentration will benefit human health and help mitigate climate warming.

VOCs are emitted to the atmosphere from a variety of anthropogenic and biogenic sources. After emission, they undergo complex chemical and physical transformations in the atmosphere. VOCs act as fuels for photochemical reactions that produce ozone (O_3) and $PM_{2.5}$, both of which are criteria pollutants and have adverse effects on human health. VOCs are composed of hundreds of thousands of molecules with different functionalities. Among the VOC compounds, BTEX is a unique group of aromatic VOCs consisting of benzene, toluene, ethylbenzene, and xylenes. BTEX compounds are of particular concern because of their high atmospheric concentrations and their potential carcinogenic effects. Among BTEX compounds, benzene is the most hazardous and has been categorized as a known human carcinogen by the International Agency for Research on Cancer.[8] Therefore, understanding the sources of atmospheric VOCs, in particular BTEX, is key to air quality management.

ii. Long-Term Trends

Trends of ambient BC, BTEX, and total VOC were evaluated prior to the source apportionment analysis. Information on the SNAPS ambient air monitoring plan for Lost Hills

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[6] Bond et al. (2013). Bounding the role of black carbon in the climate system: A scientific assessment. Journal of Geophysical Research: Atmospheres, 118: 1-173.

[7] Janssen et al. (2011). Black carbon as an additional indicator of the adverse health effects of airborne particles compared to PM_{10} and $PM_{2.5}$. Environmental Health Perspectives, 119: 1691–1699.

[8] IARC (1987). Overall evaluations of carcinogenicity: An updating of IARC Monographs volumes 1 to 42. IARC Monogr Eval Carcinog Risks Hum Suppl, 7: 1–440. PMID:3482203

can be found on the SNAPS program website.[9] VOC speciation and a list of other measured variables can also be found in Appendix Table C.3.

Figure C.6 represents the daily average BC, BTEX, and total VOC observed over the study period. Daily average BC levels were generally lower in the summer and higher in the winter, particularly in November. The variabilities of daily average BC were more pronounced during the winter months (± 0.2 μg m^{-3}) compared to the summer months (± 0.05 μg m^{-3}) suggesting that seasonality (e.g. activities that lead to emissions, meteorology) played a critical role in Lost Hills. The seasonality of BC is likely driven by a combination of seasonal human activities and monthly variations in atmospheric turbulence, where warmer months are typically associated with higher turbulence, thus further diluting air pollution, and cooler months are typically associated with lower turbulence, which can lead to the build-up of air pollution at the surface (Figure C.13).

Daily average BTEX gradually increased from May to September 2019 and observed increasing monthly variabilities over time (0.6 ± 0.3 μg m^{-3} in May and 2.0 ± 1.2 μg m^{-3} in September). BTEX stabilized thereafter until March 2020 but remained elevated by approximately two times the BTEX levels observed in summer 2019, which may have been caused by a combination of changing O&G activities (Figure C.3) and meteorological conditions.

Atypical VOC levels were observed in September 2019, where the daily average total VOC levels increased by over 10 times compared to observations in any other months albeit with few exceptions. Such anomalies were dominated by contributions from light alkanes (e.g. ethane, propane, i-butane, n-pentane). The monthly linear regressions of methane (CH_4) to ethane, propane, i-butane, and n-pentane for September 2019 showed stronger correlations (square of Pearson product-moment correlation coefficient [RSQ] = 0.80 ± 0.09) compared to the monthly linear regressions for June (RSQ = 0.79 ± 0.03), July (RSQ = 0.68 ± 0.14), and August (RSQ = 0.55 ± 0.21). This suggested the VOC enhancements toward the end of September 2019 may be strongly associated with O&G operations. Similar monthly linear regressions between carbon monoxide (CO) and the light alkanes resulted in weak correlations (RSQ < 0.1), indicating that fossil fuel combustion was not a likely source of the VOC enhancement observed in September 2019. See Figure C.14 for the monthly regression results. Similar to BTEX, the daily average total VOC levels stabilized after September 2019 but remained elevated by approximately two times the total VOC levels observed in summer 2019.

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[9] https://ww2.arb.ca.gov/our-work/programs/study-neighborhood-air-near-petroleum-sources

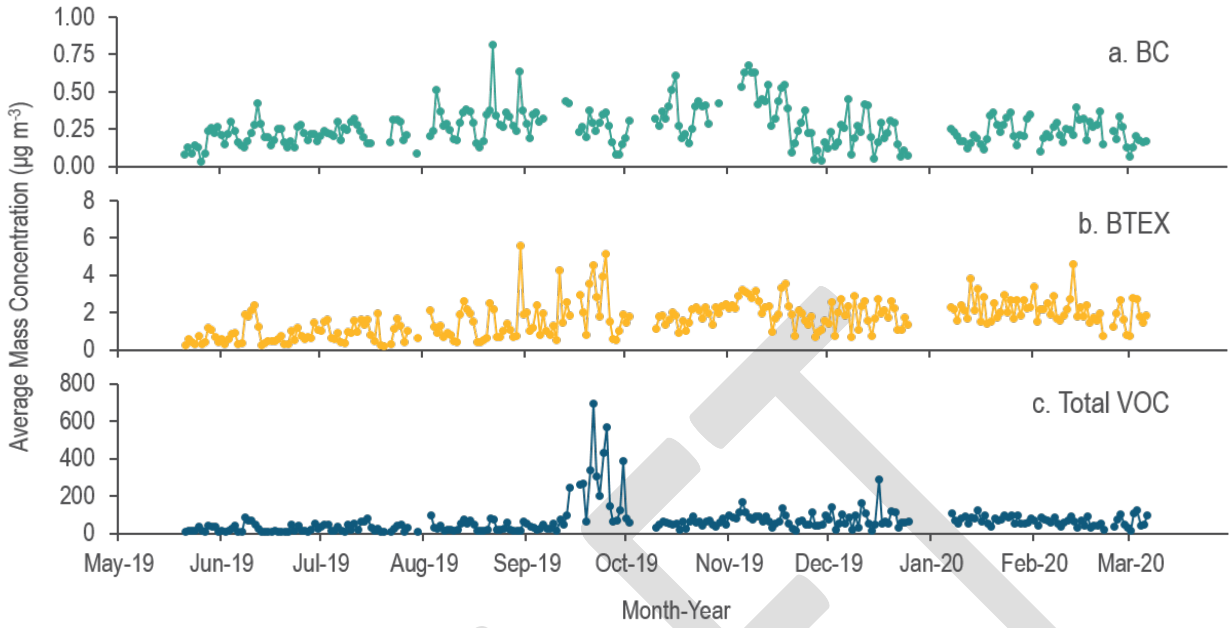

Figure C.6 Daily average mass concentration of a) BC, b) BTEX, and c) total VOC during SNAPS ambient air monitoring at Lost Hills, CA. Note that data past March 6, 2020, were not reported to avoid inferences about the air quality after Executive Order N-33-20.[10]

iii. Diurnal Patterns

Average BC levels peaked in the morning (5 – 8 AM) and the afternoon (4 – 9 PM) (Figure C.7). A combination of the air pollutants' diurnal variabilities; PC and truck VMTs; and meteorological data suggests that the peaks were closely aligned with the time of day when mobile sources became active and the atmospheric mixing height began to grow as a result of increasing surface temperatures (5 and 7 AM; Figure C.15). Typical atmospheric conditions concentrate the local air pollution at the surface during sundown and dilute it during the daylight hours. As such, BC levels were at their lowest during mid-day despite the relatively higher level of expected human activities. BC levels decreased after the evening peak, likely due to its sources being turned off and or wind direction shifting from north to west.

Average BTEX levels peaked in the early morning (3 – 7 AM) and decreased to their lowest levels during mid-day. The morning peaks ranged from 2 to 4 μg m^{-3}, while its lowest levels were approximately three times lower (Figure C.7). Subsequently, BTEX levels increased during the rush hours and remained relatively elevated past 5 PM. Lost Hills experienced preferential wind patterns that brought southwesterly to westerly air mass toward the receptor site during early morning and evening hours (e.g. O&G emissions) and northern air

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[10] https://covid19.ca.gov/img/Executive-Order-N-33-20.pdf

mass toward the receptor site during the day time (e.g. mix of traffic, residential, and agricultural emissions). It is plausible that the relatively elevated BTEX levels during the evening hours were caused by sources located to the west of the receptor site in combination with the evening atmospheric conditions that concentrated the surface air pollution.

Average total VOC levels behaved similarly to BTEX but with a less pronounced peak in the morning. The retention of elevated total VOC level after sundown may be closely associated with sources located toward the western side of Lost Hills (see wind trajectories in Figure C.5), and the evening atmospheric conditions that concentrate surface air pollution. Since total VOC is comprised of light hydrocarbons as well as more complex aromatic hydrocarbon species emitted at varying rates from various sources, the diurnal patterns may not represent the pattern of all chemicals that are emitted within and near Lost Hills.

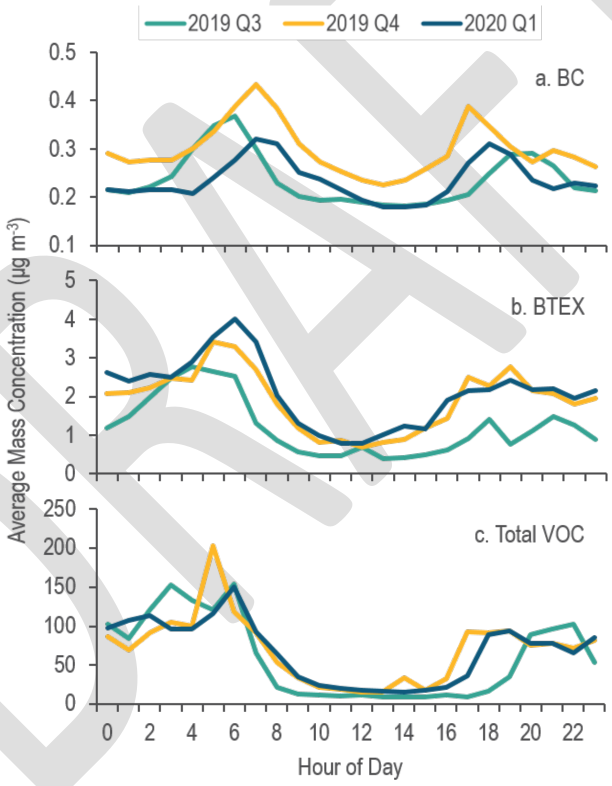

Figure C.7 Diurnal patterns of a) BC, b) BTEX, and c) total VOC for each quarter of SNAPS ambient air monitoring in Lost Hills.

f. Source Apportionment Analysis

U.S. Environmental Protection Agency (EPA) Positive Matrix Factorization (PMF) model version 5.0 is a multivariate factor analysis tool that mathematically deconstructs ambient air monitoring data and yields multiple "chemical profiles" and "contribution time series". Each pair is called a Factor: a combination of information that describes the influence of potential sources/source types/source categories on air quality observed at a receptor site. PMF also provides error estimation tools to improve the confidence in the model results. PMF is a well-established tool used by many researchers to study air quality.[11]

PMF source apportionment analyses were conducted for each quarter of the SNAPS air monitoring period to improve our understanding of the influence of seasonal human activities, source contribution patterns, and atmospheric processes that affect the air quality over the receptor site. The PMF-resolved Factors were each assigned to a source category based on the chemical profiles and the contribution time series in combination with literature review, pattern assessment, CPF, and statistical comparisons of the Factor chemical profiles to the EPA SPECIATE 5.1 database (Figure C.8). The SPECIATE database contains over 6,700 chemical profiles of various emission source types, of which over 2,500 are focused on gaseous species.[12] It is used to develop air quality model(s) and the National Emission Inventory (NEI) by the EPA. An expert interpretation is required to assign the PMF-resolved factors to source categories based on the assortment of information. Additional information on the source apportionment analysis can be found in Appendix Section h.ii and the EPA PMF User Guide.

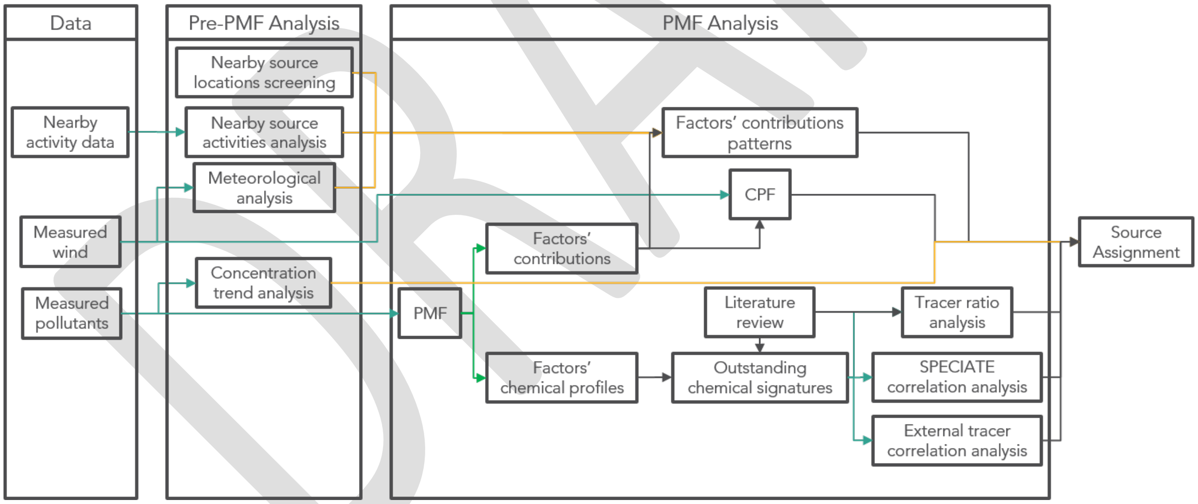

Figure C.8 Flow chart describing source assignment process.

Seven, eight, and eight stable Factors were resolved for 2019 Q3, 2019 Q4, and 2020 Q1 in this PMF source apportionment analysis, respectively. These solutions were selected based

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[11] https://www.epa.gov/air-research/positive-matrix-factorization-model-environmental-data-analyses

[12] U.S. EPA SPECIATE Database. https://www.epa.gov/air-emissions-modeling/speciate

on their stability, residual error assessment, and bootstrapping/error estimation results. Based on the subsequent source assignment process, eleven relatively unique Factors were resolved with multiple common Factors under the mobile sources and O&G operations categories in all three quarterly PMF analyses (Table C.1). Detailed justifications of the source assignment can be found in Appendix Section h.iii.

Table C.1 Source categories assigned to PMF-resolved Factors in each analysis period.

Source Category	Factor #	Quarters		
		2019 Q3	2020 Q4	2020 Q1
Mobile Sources	1	X	X	X
	2	X	X	X
	3		X	X
	4		X	
O&G Operations	1	X	X	X
	2	X	X	X
	3	X	X	X
	4		X	X
	5	X		
	6			X
Biogenic Sources	1	X		

Note that PMF source apportionment analysis is one of many techniques that can be used to evaluate the potential influence of sources on air quality observed at a receptor site. Its performance is typically limited by the list of chemical compounds that are measured at a receptor site; understanding of source-level activities data; accurate characterization of the emissions; understanding of background contributions; and complexity of atmospheric processes that affect the air pollutants in the atmosphere (e.g. chemistry, transport, meteorology). The PMF model is not a chemical transport model (CTM) and therefore does not account for atmospheric processes in the analysis that lead to losses/transformations of directly emitted air pollutants. As the polluted air travels from the source to the receptor site, chemicals react at varying rates which adds to the uncertainties in source assignment and PMF-resolved Factor representation. The potential co-location and natural mixing of various air pollutant emissions increase the chances of PMF producing Factors that represent mixed source contributions. Therefore, the information presented in this report should be used with caution, and all caveats should be considered prior to further interpretation of the results.

The sections below describe the summary of the aggregated results from all three-quarters of the PMF analyses, with a primary focus on BC, BTEX, and total VOC.

i. BC Contribution

The results indicated that mobile sources dominated the contributions to BC in all three quarters during the Lost Hills SNAPS ambient air monitoring (Figure C.9). BC is a directly emitted air pollutant closely associated with the combustion of petroleum fuels and biomass instead of evaporative or fugitive emissions. Although O&G operations such as flaring can be a source of combustion signature, PMF results suggested that O&G operations near Lost Hills contributed to a relatively minor fraction of BC compared to mobile sources. Other BC sources likely exist in the region (e.g. biomass burning), but were not resolved in the PMF analysis due to the limitations of the model and the data. Based on absolute values, BC contributions from mobile sources increased by 0.10 µg m^{-3} from 2019 Q3 to 2019 Q4 level followed by a reduction of 0.07 µg m^{-3} down to 2020 Q1 level. Quarterly averaged truck and PC VMT on SR 46 and I-5 near Lost Hills varied by approximately ± 5% and ± 10%, respectively, which may be partially responsible for the differences between the ambient BC levels in addition to the meteorological conditions that typically concentrate surface air pollution during cooler months. However, complex atmospheric processing can result in air quality data prone to errors in the model and caveats should be used when interpreting non-dominant features in the PMF results between the three quarters.

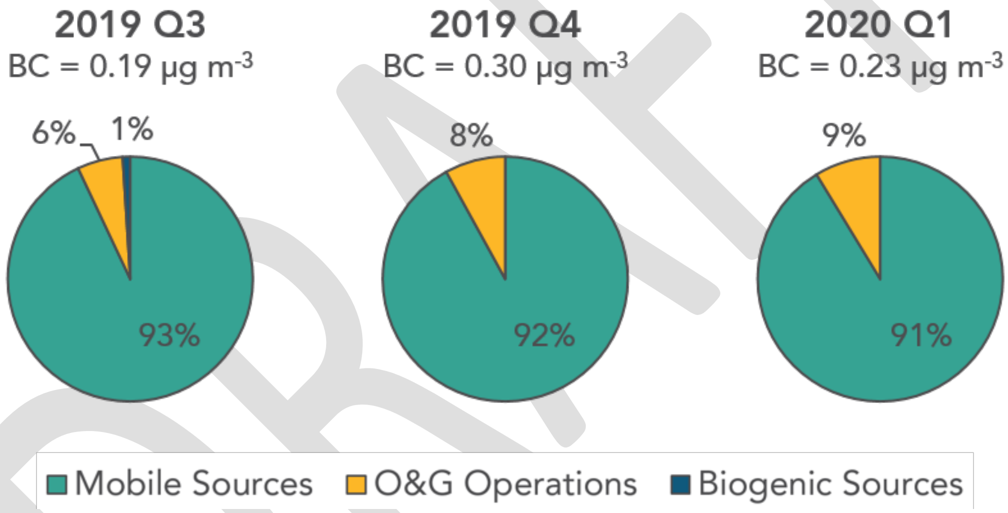

Figure C.9 Quarterly BC contribution from mobile sources, O&G operations, and biogenic sources. The concentrations represent the quarterly sum.

ii. BTEX Contribution

The results indicated that mobile sources and O&G operations dominated the BTEX contributions in all three quarters during the Lost Hills SNAPS ambient air monitoring (Figure C.10). Mobile sources contributed to a smaller fraction (44%) of BTEX in 2019 Q3, but its fractional contributions increased in later quarters. Based on absolute values, mobile sources contributed to approximately three times the 2019 Q3 level in both 2019 Q4 and 2020 Q1. O&G operations contributed to the largest fraction (55%) of BTEX in 2019 Q3, but its fractional contributions decreased in later quarters. Based on absolute values, O&G operations also contributed to approximately three times the 2019 Q3 level in both 2019 Q4 and 2020 Q1. Part of the simultaneous shift in contributions from mobile sources and O&G

operations may have resulted from seasonal temperature changes that indirectly affected the air quality by diluting or concentrating the air pollution near the surface during warmer and cooler months, respectively (Figure C.13). It is important to note that m/p-xylene was not included in the PMF analysis for 2019 Q3 due to its weak QAQC results, which inherently biased the overall 2019 Q3 BTEX levels to be lower (see Appendix Section h.iii). In 2019 Q4 and 2020 Q1, mobile sources and O&G operations had m/p-xylene apportioned to ~16 - 19% of their BTEX fractions. Although m/p-xylene was a relatively smaller fraction of the BTEX, the PMF results may vary if m/p-xylene passed the QAQC and was included in the model. Such a scenario was not evaluated for 2019 Q3 and therefore caution should be used in interpreting the BTEX results between the three quarters.

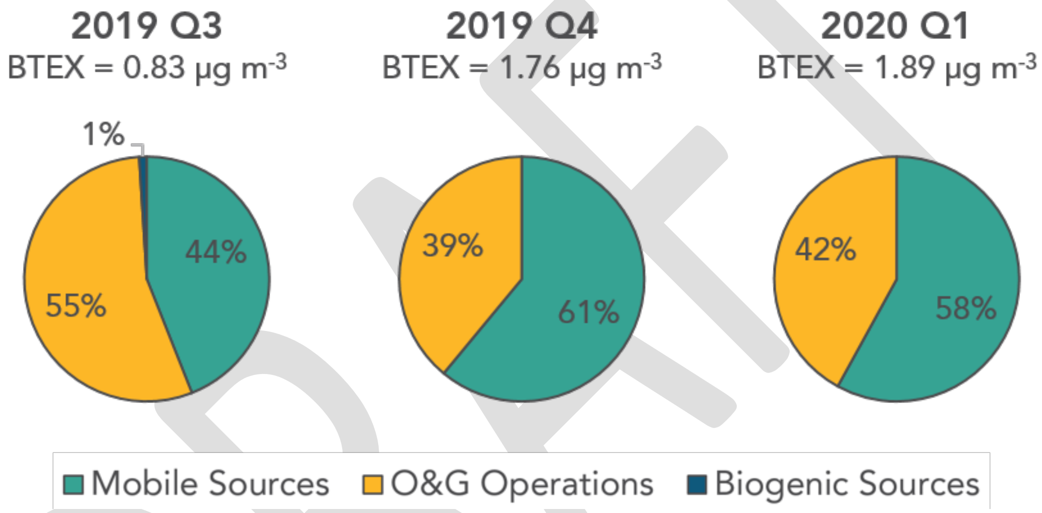

Figure C.10 Quarterly BTEX contribution from mobile sources, O&G operations, and biogenic sources. The concentrations represent the quarterly sum.

iii. Total VOC Contribution

The results indicated that O&G operations dominated the total VOC contributions in all three quarters during the Lost Hills SNAPS ambient air monitoring (Figure C.11). VOC levels were primarily driven by the abundance of light alkanes (e.g. ethane, propane, i-butane, n-pentane) apportioned to Factors representing both mobile sources and O&G operations. Although a consistent set of VOC species were measured throughout the SNAPS ambient air monitoring period, quarterly QAQC processes produced refined VOC datasets that were unique to each of the quarterly PMF analyses. Only those VOC species that passed the QAQC procedures were used (Appendix Section h.ii and the EPA PMF User Guide). Therefore, it was important to consider the relative importance of the individual chemical species prior to interpreting the total VOC results. Under many circumstances, chemical compounds identified as hazardous air pollutants (HAPs) may not dominate the total VOC mass. In addition to cooler weather indirectly concentrating the air pollution at the surface, it is possible that the shift in O&G operations during the Fall of 2019 caused the total VOC to increase in subsequent quarters (see Figure C.3). Data describing the speciated VOC contributions for each quarter can be found in Appendix Section h.iii.

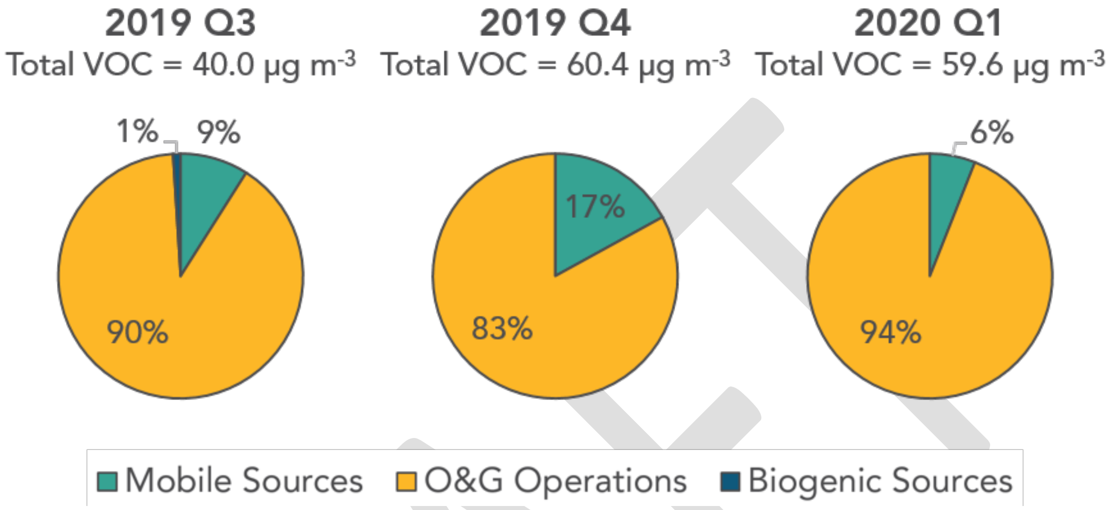

Figure C.11 Quarterly total VOC contribution from mobile sources, O&G operations, and biogenic sources. The concentrations represent the quarterly sum.

iv. Diurnal Patterns by Source Categories

The relative diurnal patterns suggested that the mobile sources influenced ambient BC, BTEX, and total VOC levels particularly during the early morning between 5 and 7 AM and in the afternoon between 5 and 8 PM depending on the season (Figure C.12). Although mobile sources were consistently active around the region, the peaks were consistent with the general human activity patterns (e.g. morning and afternoon rush hours); the shift in meteorology during sunrise and sunset that transported air from different regions toward the receptor site (Figure C.5); and concentration of the surface air pollution during the nighttime (Figure C.15). Note that the PMF analyses did not perform background subtractions on the ambient air monitoring data due to a lack of upwind measurements. Upwind air can be influenced by a variety of air pollutant sources and atmospheric processes before reaching the receptor site, leading to residual uncertainties in the PMF results. It is, therefore, appropriate to assume that all PMF-resolved Factors are influenced by the background air in some way. See Section h for more details.

O&G operations were associated with relatively consistent BC, BTEX, and total VOC enhancements during evening hours compared to mid-day likely due to meteorology that preferentially transported air from the west of Lost Hills (Figure C.5). Peaks from O&G operations, if any, occurred slightly earlier than the peaks associated with mobile sources. Contributions from O&G operations during mid-day were minor compared to the evening hours since O&G operations do not exist in large clusters immediately to the north of Lost Hills where daytime air travels from.

Biogenic contributions were observed most notably in 2019 Q3 around 9 PM, which continued into the evening hours. CPF assessment suggests that the contributions may have been influenced by biomass burning as well as mid-range transport of air mass from the west coast, transporting biogenic emissions into the valley as it mixed with air influenced by regional air pollutant sources such as industrial operations, mobile sources, and biomass burning in the Valley.

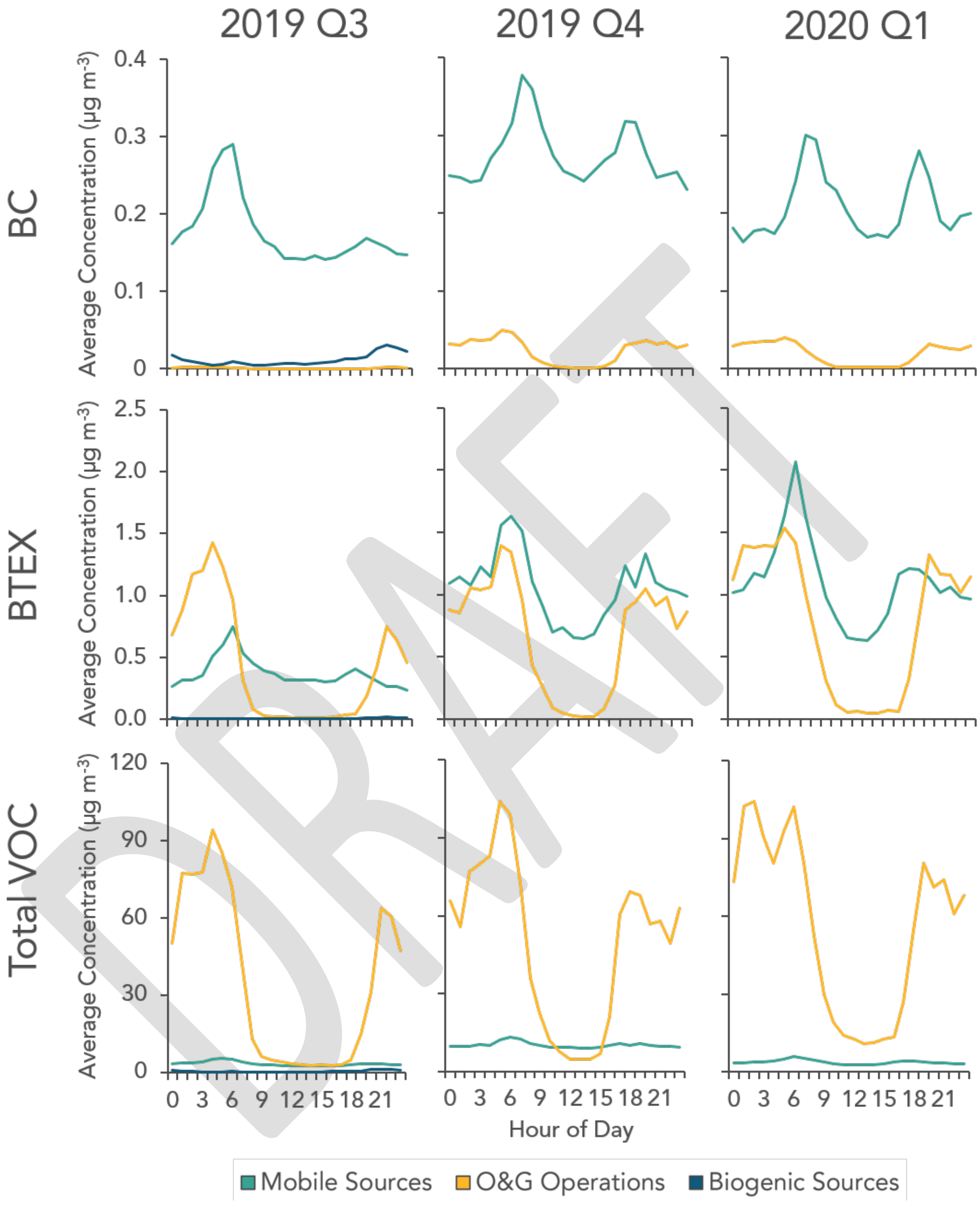

Figure C.12 Quarterly BC, BTEX, and VOC diurnal pattern from mobile sources, O&G operations, and biogenic sources. The concentrations represent the quarterly average for each hour.

g. Summary

The source apportionment analysis of the separate quarters, although conducted individually, resulted in generally consistent results; O&G operations were responsible for 1 – 9% of BC, 39 – 55% of BTEX, and 83 – 94% of total VOC. On the other hand, mobile sources were responsible for 91 – 93% of BC, 44 – 61% of BTEX, 6 – 17% of total VOC (Table C.2).

Table C.2 Summary of the source apportionment results.

Quarter	Contributions					
	BC		BTEX		Total VOC	
	O&G	Mobile	O&G	Mobile	O&G	Mobile
2019 Q3	1%	93%	55%	44%	90%	9%
2019 Q4	8%	92%	39%	61%	83%	17%
2020 Q1	9%	91%	42%	58%	94%	6%

This analysis also concluded that wind direction and atmospheric turbulence played an important role in Lost Hills. It is expected that the region would continue to experience similar meteorological patterns observed during the SNAPS ambient air monitoring. O&G operations were the dominant influencer of air quality during evening hours when the winds traveled from the southwest and west of Lost Hills. On the other hand, mobile sources became the dominant influencer of air quality during early mornings and early evenings when the wind traveled from the north and northeasterly region. Nighttime and cooler months experienced higher air pollution levels than daytime and warmer months. In addition to exploring potential emission reduction options, reducing indoor-outdoor air exchanges during cooler evening hours may significantly reduce air pollution exposure. Meteorology is complex in the San Joaquin Valley and therefore additional caveats should be made when interpreting the results in the context of sources located farther away from the receptor site.

The PMF model was able to generate relatively unique Factors that described the two major source categories despite apparent residual influences in the PMF output. Measuring more species that act as markers or tracers for other various source categories could significantly facilitate the source assignment process and potentially resolve Factors with higher confidence. Additional caveats are presented in the Source Apportionment Appendices.

h. Source Apportionment Appendices

Table C.3 Full list of variables measured at the SNAPS Lost Hills ambient air monitoring site used in the PMF analysis.

Class	Parameters
Gas	methane
Gas	hydrogen sulfide
Particle	$PM_{2.5}$
Gas	ozone
Particle	black carbon
Gas	carbon monoxide
Meteorology	N-S Wind (Vector)
Meteorology	E-W Wind (Vector)
Meteorology	Temperature
Gas	ethane
Gas	ethene
Gas	propane
Gas	propylene
Gas	isobutane
Gas	n-butane
Gas	acetylene
Gas	trans-2-butene
Gas	1-butene
Gas	cis-2-butene
Gas	cyclopentane
Gas	2-methylbutane
Gas	n-pentane
Gas	trans-2-pentene
Gas	1-pentene
Gas	cis-2-pentene
Gas	2,2-dimethylbutane
Gas	2,3-dimethylbutane
Gas	2-methylpentane
Gas	3-methylpentane
Gas	isoprene
Gas	1-hexene
Gas	methylcyclopentane
Gas	n-hexane
Gas	benzene
Gas	cyclohexane
Gas	2,4-dimethylpentane
Gas	2,3-dimethylpentane
Gas	2-methylhexane
Gas	3-methylhexane
Gas	methylcyclohexane
Gas	n-heptane
Gas	toluene
Gas	2,2,4-trimethylpentane
Gas	2,3,4-trimethylpentane
Gas	2-methylheptane
Gas	3-methylheptane
Gas	n-octane
Gas	ethylbenzene
Gas	m/p-xylene
Gas	styrene
Gas	o-xylene
Gas	isopropylbenzene
Gas	n-nonane
Gas	n-propylbenzene
Gas	1,3,5-trimethylbenzene
Gas	m-ethyltoluene
Gas	1,2,4-trimethylbenzene
Gas	p-ethyltoluene
Gas	o-ethyltoluene
Gas	1,2,3-trimethylbenzene
Gas	n-decane
Gas	p-diethylbenzene
Gas	m-diethylbenzene
Gas	n-undecane
Gas	n-dodecane

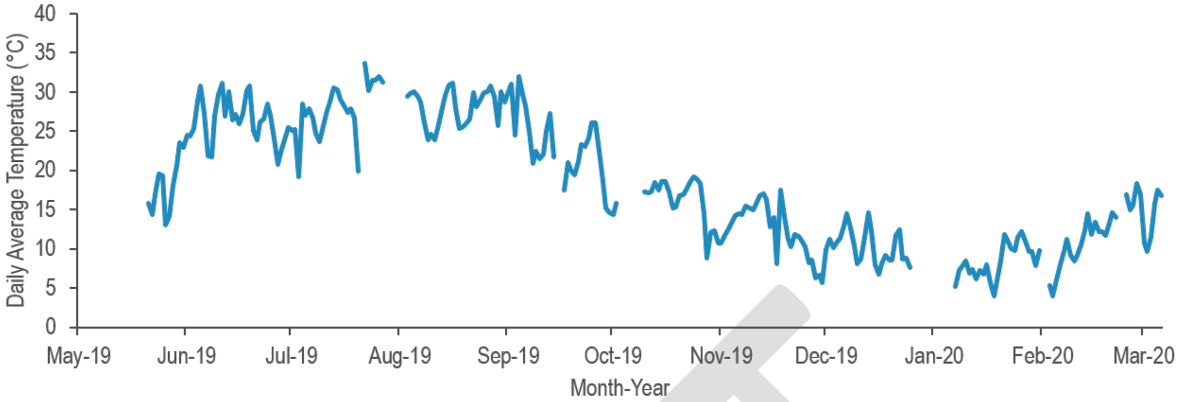

Figure C.13 Daily average temperature measured during SNAPS ambient air monitoring at Lost Hills, CA.

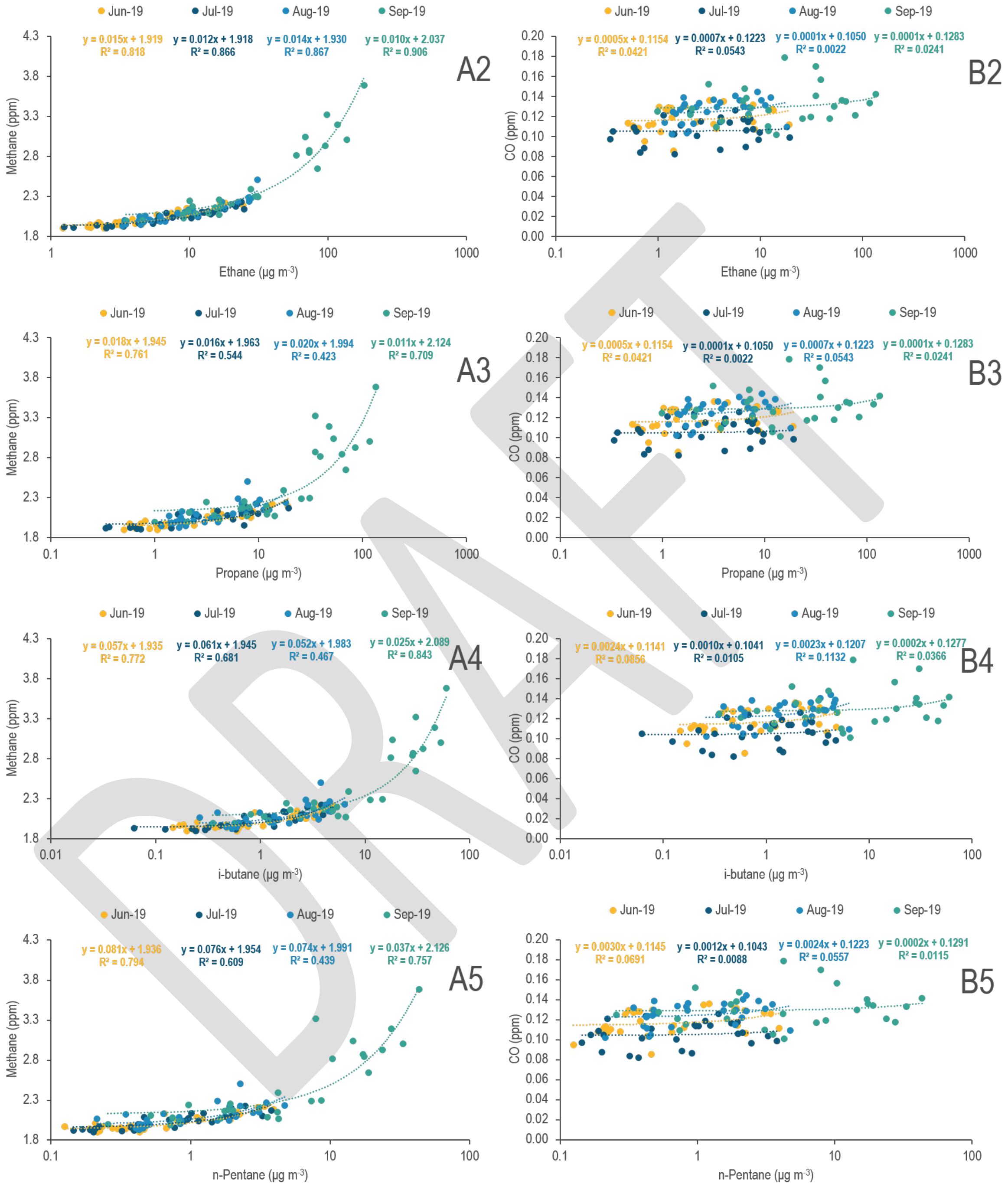

Figure C.14 Monthly linear regression analysis between CH_4:C2-C5 alkanes and CO:C2-C5 alkanes for 2019 Q3. A and B correspond to CH_4 and CO as variables for the y-axis, respectively. Numbers 2-5 correspond to ethane (C_2H_6), propane (C_3H_8), i-pentane (C_4H_{10}), and n-pentane (C_5H_{12}), respectively.

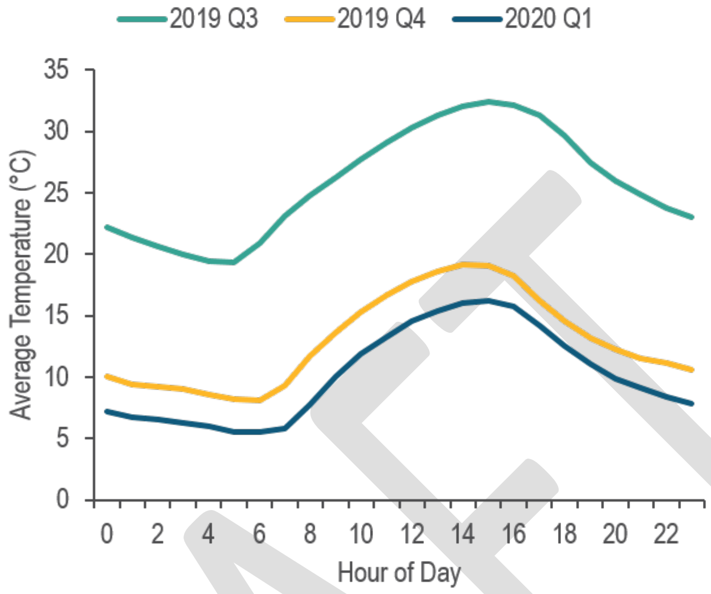

Figure C.15 Diurnal average temperature change in each quarter of SNAPS ambient air monitoring at Lost Hills, CA.

i. Probability Statistics of Regional PC and Truck Activities during 2020 Q1

Weekly average diurnal traffic volume (PC and truck) from PeMS was used to identify the week in which on-road transportation activities diverged away from typical conditions in District 6 as a result of the state's response to the COVID-19 pandemic. T-tests were calculated for each week in 2020 relative to another. The i-th week that consistently resulted in weak statistics, particularly with its prior weeks' traffic activities, was identified as the drop-off week (i.e. week when traffic activity changed dramatically). Week of i minus 1 was deemed the cut-off week; the week in which data analysis ended.

Both PC and truck VMT dropped off significantly on the 12th week (i = 12) of 2020 based on the weekly average VMT reduction and averaged t-test probability that support the deviating behavior of traffic activities compared to prior weeks (Figures C.16; C.17). To remove the influence of such volatile transportation activities during the state's shelter-in-place order, source apportionment analysis did not include data past the 11th week (i –1 = 11), or March 9, 2020.

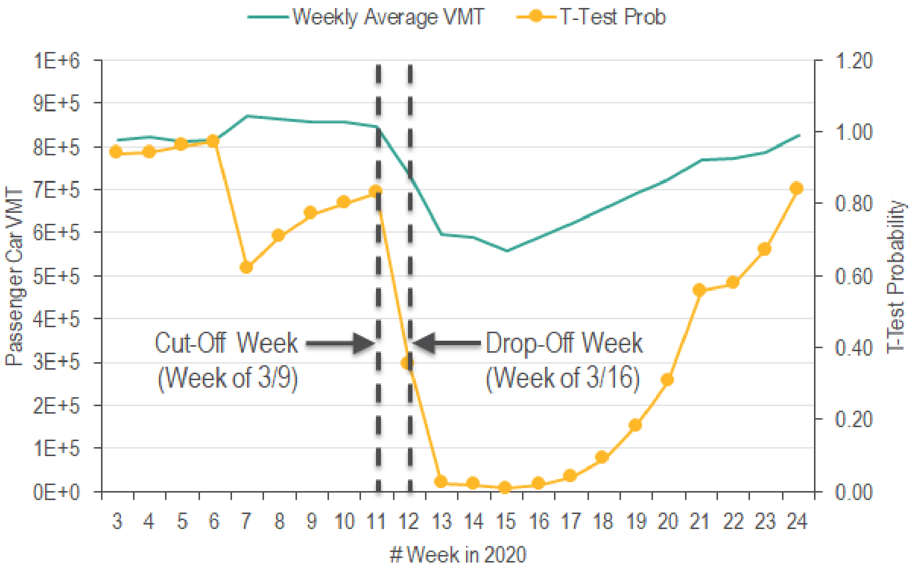

Figure C.16 Passenger car VMT and aggregated t-test probability. Large drop-off VMT and t-test probability values suggest that traffic volume decreased significantly away from typical conditions.

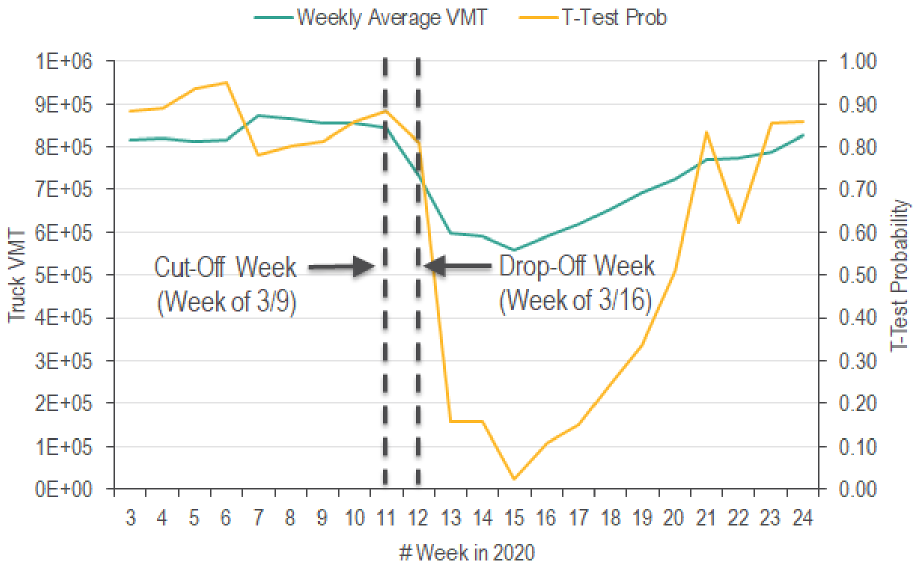

Figure C.17 Truck VMT and aggregated t-test probability. Large drop-off VMT and t-test probability values suggest that traffic volume decreased significantly away from typical conditions.

ii. Source Apportionment Analysis Methods

The following section describes the three-tiered source apportionment analysis protocol compiled by CARB staff to evaluate the SNAPS ambient air monitoring data. The protocol consisted of three steps; 1) pre-processing of the input files, 2) PMF runs, and 3) source identification and evaluation of results. In step 2, a matrix of independent PMF runs with varying numbers of factor solutions (5, 6, 7, 8, and 9) was evaluated. Solutions with the lowest residual errors and the most robust error estimation results were considered for further evaluation. Details of these steps are described below.

1. Pre-Processing of Input Files

In this step, meteorological variables (temperature and wind), species with secondary-formation characteristics ($PM_{2.5}$ and O_3), and species with high background levels (CH_4) were removed from the PMF analysis. The remaining species included BC, carbon monoxide (CO), ethane, and various VOCs. In addition, potential influences of hyperlocal sources were removed from the input files by detecting concentration values that are greater than 3 times the maximum of their adjacent values and replacing them with the average of the adjacent values. For example, if the ambient ethane level at 2 PM on 10/1/2019 was at least 3 times greater than the maximum of its levels at 1 and 3 PM, the concentration at 2 PM was replaced by the average of the values at 1 and 3 PM.

2. PMF Source Apportionment

In this step, independent PMF runs were conducted for varying numbers of factors. For each number of factors, the following steps were done to yield a stable solution:

a. **Datapoint removal:** Further exclusion of data by visually inspecting species time series and detecting peaks suspected to be caused by hyperlocal sources,

b. **Species removal:** Per PMF user's guide, species with a poor signal-to-noise ratio (S/N) were marked "bad" (< 0.5; excluded from analysis) or "weak" (> 0.5 and < 1; tripled the uncertainty levels),

c. **Iterative PMF runs:** PMF was run 20 times and the model errors were evaluated; if the correlation coefficient (r^2) between the observed and the modeled concentrations of the species were below 0.6, or its slope was outside the range of 0.7 – 1.3, the species was downweighed, i.e. marked "weak" or "bad" if it was marked "strong" or "weak", respectively. After downweighing the species, the model was run several times until all the modeled species concentrations passed the correlation coefficient and slope criteria. Further evaluations of model output such as residual analysis and G-space plot evaluation were performed per the PMF user's guide.

d. **Error evaluations:** After finding the species configuration that resulted in the most stable solution, PMF was run 100 times to find the best solution. The random errors and rotational ambiguity associated with the model output were evaluated by running the displacement method and bootstrapping (100 times) on the base run, respectively. If the errors were acceptable based on the PMF user's guide, the model output was used as the most stable solution.

3. Source Identification and Results Evaluation

CARB staff evaluated the factor chemical profiles of the most stable solutions and selected the best solution based on the robustness of the model output, factor chemical profiles, and their similarities with known source signatures. The factor chemical profiles were identified and supported following the steps below:

a. **CPF:** Using CPF to determine the relative locations of sources by evaluating the dominant wind direction when relatively high Factor contributions were observed. Wind directions were associated with Factor contributions > 75th percentile.

b. **Diurnal patterns:** Determining the diurnal variation of Factor contributions. Factors that were associated with northerly winds based on the CPF analysis had higher contributions during the daytime, supporting the hypothesis that those factors are associated with traffic activity. Factors that were associated with southerly to westerly winds based on the CPF analysis had higher contributions during nighttime, supporting the hypothesis that those factors are related to O&G operations.

c. **Source identification:** In this step, CARB staff interpreted the factor chemical profiles using marker species and source categories in SPECIATE 5.1 database.

iii. Factor Assignment

1. Mobile Source Factor 1 (confidence level = medium)

Mobile Source Factor 1 was assigned to its source category based on CO, BTEX, and 1,2,4-trimethylbenzene that are typically dominant in vehicle tailpipe emissions (see Appendix Table C.4).[13,14,15] Similar chemical profiles were resolved in all three quarters. These chemical profiles correlated with RSQ ~30–70%, demonstrating the similarities between the independently derived PMF results in each quarter. The lower RSQ values came from 2019 Q3 that also included a more complex mixture of emissions from mobile sources characterized by BC, higher CO, 1,3,5-trimethylbenzene, 2,2,3-trimethylpentane, and n-decane. 2019 Q4 and 2020 Q1 also contained combinations of 1,2,3-trimethylbenzene and ethylbenzene as notable components of the chemical profiles. The presence of n-decane and n-nonane in 2019 Q3 and 2019 Q4, respectively, suggested that the Factor may represent a combination of vehicle tailpipe emissions and residual influences from solvents, including petroleum fuel. The benzene normalized ratios for isobutane, n-butane, n-pentane, and isopentane were 0.03 – 0.49, 0 – 0.94, 0 – 0.61, and 0.65 – 1.65, which closely resembled mobile source emissions reported by Pang et al. (2014) instead of solvent-use. Caveats should be used to convey the model errors affecting the Factor chemical profiles.

The CPF analysis associated elevated Factor contributions with northeasterly, westerly, and southeasterly winds (Figure C.18). In general, these directions are consistent with the locations of SR 46 and Lost Hills residential areas with respect to the receptor site. Although residual influences from O&G operations are possible, this Factor had a relatively low correlation with ambient CH_4 levels (RSQ ~0.06–0.11), suggesting that O&G operations are not strongly associated with this Factor. The diurnal profile of the Factor shows similar or higher nighttime air pollutant levels than the daytime, with one peak in the early morning and another one in the late evening. This diurnal pattern was consistent with the human activities related to transportation and the atmospherically transient period when the atmospheric mixing regime switched from nighttime to daytime and vice versa.

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[13] Dumanoglu, Y., Kara, M., Altiok, H., Odabasi, M., Elbir, T., & Bayram, A. (2014). Spatial and seasonal variation and source apportionment of volatile organic compounds (VOCs) in a heavily industrialized region. *Atmospheric Environment*, *98*, 168–178. https://doi.org/10.1016/j.atmosenv.2014.08.048

[14] Pang, Y., Fuentes, M., & Rieger, P. (2014). Trends in the emissions of Volatile Organic Compounds (VOCs) from light-duty gasoline vehicles tested on chassis dynamometers in Southern California. *Atmospheric Environment*, *83*, 127–135. https://doi.org/10.1016/j.atmosenv.2013.11.002

[15] Shao, P., An, J., Xin, J., Wu, F., Wang, J., Ji, D., & Wang, Y. (2016). Source apportionment of VOCs and the contribution to photochemical ozone formation during summer in the typical industrial area in the Yangtze River Delta, China. *Atmospheric Research*, *176–177*, 64–74. https://doi.org/10.1016/j.atmosres.2016.02.015

Table C.4 Quarterly PMF chemical profiles for Mobile Source Factor 1. Boxes colored in gray indicate chemical compounds not included in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

Mobile Source Factor 1						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	7.18E-02	38.0	0.00E+00	0.0	0.00E+00	0.0
CO	3.86E+01	32.5	1.02E+01	6.4	1.22E+01	7.6
ethane	2.45E-02	0.3	6.13E-01	3.7	0.00E+00	0.0
propane	7.01E-02	1.0	0.00E+00	0.0	1.73E-01	1.6
isobutane	6.12E-02	1.9	2.50E-03	0.1	1.43E-02	0.4
n-butane	0.00E+00	0.0	0.00E+00	0.0	7.12E-02	1.2
acetylene	-	-	0.00E+00	0.0	3.51E-02	11.8
cyclopentane	0.00E+00	0.0	3.56E-02	5.0	2.30E-02	3.3
2-methylbutane	8.24E-02	2.8	1.25E-01	3.6	9.74E-02	2.7
n-pentane	0.00E+00	0.0	4.61E-02	1.8	0.00E+00	0.0
2,2-dimethylbutane	6.95E-03	6.7	4.12E-02	25.3	1.18E-02	7.6
2,3-dimethylbutane	3.84E-02	10.9	5.44E-02	12.7	3.19E-02	7.9
2-methylpentane	2.62E-02	3.2	8.18E-02	7.2	4.37E-02	4.0
3-methylpentane	8.73E-03	3.4	2.07E-02	3.4	2.83E-02	3.1
Isoprene	8.17E-03	2.9	-	-	-	-
methylcyclopentane	2.76E-02	2.1	1.25E-02	0.6	1.77E-02	1.0
n-hexane	3.50E-02	4.1	6.18E-03	0.5	1.88E-02	1.7
benzene	1.26E-01	58.8	7.56E-02	18.1	7.59E-02	14.7
cyclohexane	2.37E-02	4.3	1.00E-02	1.1	4.88E-03	0.6
2,4-dimethylpentane	2.37E-03	2.2	0.00E+00	0.0	0.00E+00	0.0
2,3-dimethylpentane	1.14E-02	4.7	7.03E-02	20.1	1.27E-02	4.0
2-methylhexane	2.33E-02	8.7	5.97E-02	17.0	2.53E-02	8.0
3-methylhexane	3.03E-02	8.3	5.43E-02	11.7	2.75E-02	6.3
methylcyclohexane	0.00E+00	0.0	3.10E-02	1.9	0.00E+00	0.0
n-heptane	4.14E-03	1.1	4.93E-02	10.3	1.69E-02	3.9
toluene	1.44E-01	41.9	2.00E-01	35.4	1.83E-01	30.6
2,2,4-trimethylpentane	4.72E-02	4.5	7.26E-02	4.7	4.19E-02	2.8
2,3,4-trimethylpentane	-	-	2.19E-02	26.1	1.12E-02	14.7
2-methylheptane	4.56E-03	3.0	2.07E-02	8.0	0.00E+00	0.0
3-methylheptane	8.70E-03	16.2	1.48E-02	16.5	1.02E-02	13.0
n-octane	7.81E-03	4.7	-	-	0.00E+00	0.0
ethylbenzene	2.91E-02	16.7	8.13E-02	26.6	7.96E-02	27.0
m/p-xylene	-	-	1.41E-01	45.8	1.89E-01	57.8
styrene	-	-	-	-	0.00E+00	0.0
o-xylene	3.24E-02	34.8	6.59E-02	41.6	7.65E-02	49.4
n-nonane	-	-	4.46E-02	27.7	-	-
n-propylbenzene	-	-	5.76E-03	2.2	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	1.61E-02	11.9
1,3,5-trimethylbenzene	1.41E-02	36.0	-	-	-	-
1,2,4-trimethylbenzene	3.98E-02	30.7	9.57E-02	45.9	6.87E-02	33.9
1,2,3-trimethylbenzene	2.71E-02	10.5	1.16E-01	33.0	3.06E-02	12.3
n-decane	1.77E-02	27.0	-	-	-	-
m-diethylbenzene	-	-	0.00E+00	0.0	-	-

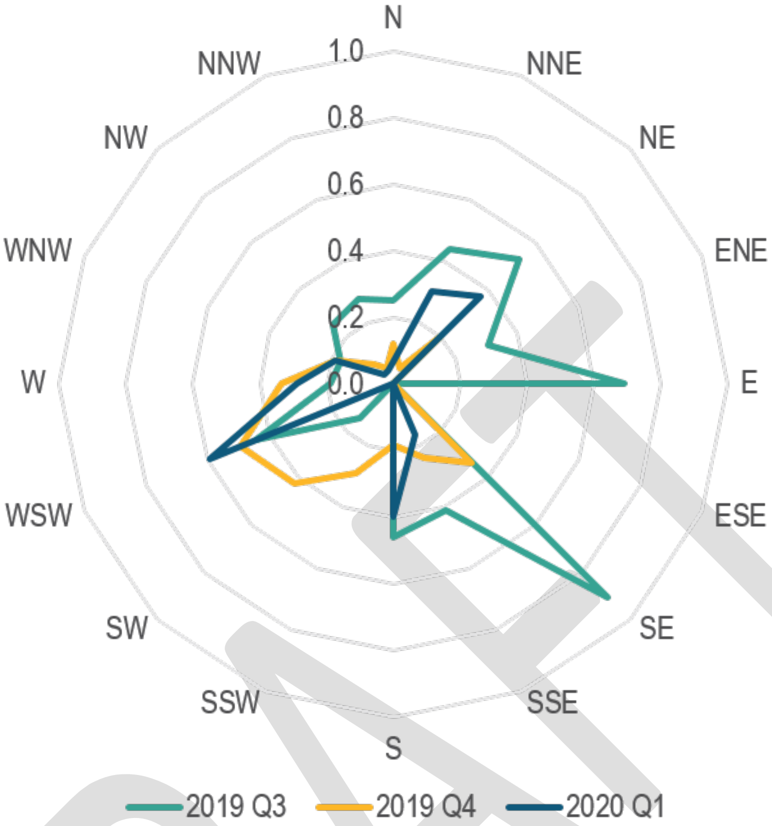

Figure C.18 Quarterly CPF for Mobile Source Factor 1. The wind directions were associated with Factor contributions > 75th percentile.

2. Mobile Source Factor 2 (confidence level = high)

Mobile Source Factor 2 was assigned to its source category based on its contributions from BC, CO, 2,2(3)-dimethylbutane, and minor influences from 1,2,4-trimethylbenzene, which are typical markers for vehicle tailpipe emissions (see Appendix Table C.5).[16,17,18] Although 2019 Q4 was associated with BTEX, 2019 Q3 lacked the contributions of benzene and o-xylene, and 2020 Q1 lacked the contributions of xylenes with a minor contribution of ethylbenzene. 2019 Q3 PMF results were also associated with n-octane and n-heptane (signatory of gasoline fuel) suggesting that the Factors for each of the quarter resolved slightly different mixtures of mobile source emissions. For instance, 2019 Q3 chemical profile provides evidence of contribution from evaporative fuel emissions, potentially caused by higher ambient temperatures. 2020 Q1 results also included acetylene, which improved the confidence in the Factor assignment.[19,20] The RSQ between the chemical profiles of the three quarters was between 0.41–0.93, with the weakest correlations observed for 2019 Q3 comparisons. Since the ensemble information suggests that the Factor represents mobile source emissions and petroleum fuel product of unknown source category, a caveat should be used when inferring information about Mobile Source Factor 2 beyond this report.

The CPF analysis showed that high Factor contributions were associated with northerly and northwesterly winds, consistent with the location of SR 46 with respect to the receptor site (Figure C.19). O&G operations were significantly less abundant to the north of Lost Hills. Based on the chemical profile, it is less likely that residential activities contributed significantly to this Factor. The diurnal pattern peaked in the morning (6 – 8 AM) and the late evening (~7 PM). Although the evening peak in 2019 Q3 was substantially lower, the general diurnal pattern was consistent with the human activities related to transportation and the atmospherically transient period when the atmospheric mixing regime switched from nighttime to daytime and vice versa. In addition, this Factor had a relatively low correlation

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[16] Brown, S. G., Frankel, A., & Hafner, H. R. (2007). Source apportionment of VOCs in the Los Angeles area using positive matrix factorization. *Atmospheric Environment*, *41*(2), 227–237. https://doi.org/10.1016/j.atmosenv.2006.08.021

[17] Guha, A., Gentner, D. R., Weber, R. J., Provencal, R., & Goldstein, A. H. (2015). Source apportionment of methane and nitrous oxide in California's San Joaquin Valley at CalNex 2010 via positive matrix factorization. *Atmospheric Chemistry and Physics*, *15*(20), 12043–12063. https://doi.org/10.5194/acp-15-12043-2015

[18] Leuchner, M., & Rappenglück, B. (2010). VOC source-receptor relationships in Houston during TexAQS-II. *Atmospheric Environment*, *44*(33), 4056–4067. https://doi.org/10.1016/j.atmosenv.2009.02.029

[19] Brown, S. G., Frankel, A., & Hafner, H. R. (2007). Source apportionment of VOCs in the Los Angeles area using positive matrix factorization. Atmospheric Environment, 41(2), 227–237. https://doi.org/10.1016/j.atmosenv.2006.08.021

[20] Watson, J. G., Chow, J. C., & Fujita, E. M. (2001). Review of volatile organic compound source apportionment by chemical mass balance. Atmospheric Environment, 35, 1567–1584. https://doi.org/10.1016/s1352-2310(00)00461-1

with ambient CH_4 levels (RSQ ~0.06 – 0.08), highlighting the Factor's weak association with O&G operations.

Table C.5 Quarterly PMF chemical profiles for Mobile Source Factor 2. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

Mobile Source Factor 2

Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	1.04E-01	55.1	2.48E-01	82.5	1.89E-01	83.3
CO	6.42E+01	54.0	4.47E+01	28.2	4.05E+01	25.3
ethane	1.17E+00	12.4	0.00E+00	0.0	1.53E-02	0.1
propane	0.00E+00	0.0	5.13E-01	4.5	1.73E-01	1.6
isobutane	0.00E+00	0.0	1.39E-01	3.6	1.49E-02	0.4
n-butane	8.12E-02	1.7	1.04E-01	1.6	5.50E-02	0.9
Acetylene	-	-	0.00E+00	0.0	3.77E-02	12.7
cyclopentane	7.33E-02	13.0	2.37E-02	3.3	1.31E-02	1.9
2-methylbutane	2.18E-01	7.4	2.10E-01	6.1	6.05E-02	1.7
n-pentane	1.46E-01	7.0	5.46E-02	2.1	0.00E+00	0.0
2,2-dimethylbutane	3.62E-02	35.0	1.30E-02	8.0	1.52E-02	9.8
2,3-dimethylbutane	1.36E-01	38.5	3.65E-02	8.5	2.70E-02	6.7
2-methylpentane	7.23E-02	8.8	5.23E-02	4.6	2.95E-02	2.7
3-methylpentane	4.65E-02	17.9	1.46E-02	2.4	1.75E-02	1.9
Isoprene	0.00E+00	0.0	-	-	-	-
methylcyclopentane	0.00E+00	0.0	1.81E-02	0.9	8.30E-03	0.5
n-hexane	0.00E+00	0.0	2.89E-02	2.3	3.06E-02	2.8
benzene	0.00E+00	0.0	3.96E-02	9.5	3.28E-02	6.4
cyclohexane	1.45E-02	2.6	1.91E-02	2.2	7.21E-03	0.9
2,4-dimethylpentane	8.97E-03	8.4	0.00E+00	0.0	0.00E+00	0.0
2,3-dimethylpentane	3.70E-02	15.2	2.70E-03	0.8	1.09E-02	3.4
2-methylhexane	3.50E-02	13.0	1.14E-02	3.2	1.45E-02	4.6
3-methylhexane	6.02E-02	16.5	2.78E-02	6.0	1.20E-02	2.7
methylcyclohexane	1.60E-02	1.6	0.00E+00	0.0	0.00E+00	0.0
n-heptane	6.52E-02	17.6	1.39E-02	2.9	9.86E-03	2.3
toluene	2.66E-02	7.8	1.02E-01	18.1	5.40E-02	9.0
2,2,4-trimethylpentane	2.01E-02	1.9	2.21E-02	1.4	0.00E+00	0.0
2,3,4-trimethylpentane	-	-	9.57E-03	11.4	4.88E-03	6.4
2-methylheptane	4.93E-04	0.3	2.21E-04	0.1	0.00E+00	0.0
3-methylheptane	9.05E-04	1.7	3.90E-03	4.4	0.00E+00	0.0
n-octane	6.27E-02	38.0	-	-	0.00E+00	0.0
ethylbenzene	8.45E-03	4.9	1.58E-02	5.2	1.55E-03	0.5
m/p-xylene	-	-	2.55E-02	8.3	0.00E+00	0.0
styrene	-	-	-	-	5.14E-03	4.6
o-xylene	0.00E+00	0.0	1.21E-02	7.6	0.00E+00	0.0
n-nonane	-	-	0.00E+00	0.0	-	-
n-propylbenzene	-	-	0.00E+00	0.0	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	0.00E+00	0.0
1,3,5-trimethylbenzene	0.00E+00	0.0	-	-	-	-
1,2,4-trimethylbenzene	1.34E-02	10.3	1.02E-02	4.9	1.33E-02	6.6
1,2,3-trimethylbenzene	9.65E-02	37.5	0.00E+00	0.0	1.02E-02	4.1
n-decane	9.67E-03	14.8	-	-	-	-
m-diethylbenzene	-	-	2.88E-02	7.4	-	-

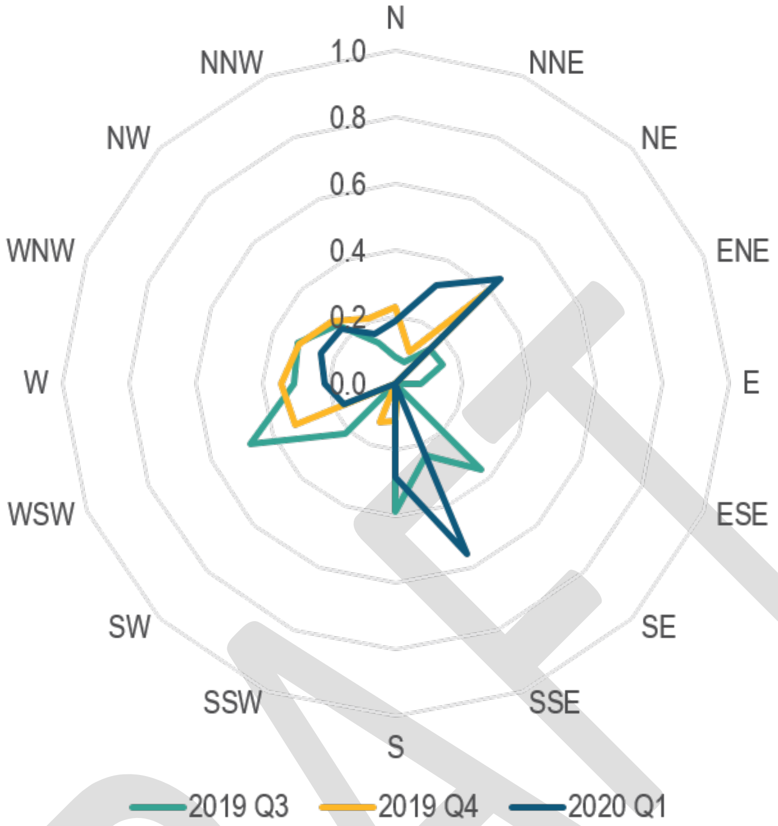

Figure C.19 Quarterly CPF for Mobile Source Factor 2. The wind directions were associated with Factor contributions > 75th percentile.

3. Mobile Source Factor 3 (confidence level = high)

Mobile Source Factor 3 was assigned its source category based on contributions from CO and acetylene, with less prominent contributions from benzene, toluene, m-diethylbenzene, and light alkanes (e.g. ethane, propane, n-butane) (see Appendix Table C.6). Previous studies suggested that vehicle exhaust is the major source of CO and acetylene.[21,22] This Factor was not resolved in 2019 Q3 partially due to the lack of acetylene which did not pass the QAQC process. Comparison of the Factor chemical profiles between 2019 Q4 and 2020 Q1 resulted in RSQ > 0.75, demonstrating that both quarterly PMF analyses produced similar results. The ratios of ethane to propane in this Factor were 1.71 and 1.43 for 2019 Q4 and 2020 Q1, respectively. These values were similar to those of the O&G source profiles represented in the SPECIATE database (particularly O&G production) suggesting that the factor may contain residual influences from O&G operations. However, this Factor had negligible correlations with ambient CH_4 levels (RSQ < 0.05) and the likelihood of this Factor being associated with the general O&G activities was low.

The CPF analysis also associated elevated Factor contributions with northeasterly, southeasterly, and northerly winds, consistent with the locations of SR 46 and residential areas in Lost Hills with respect to the receptor site (Figure C.20). Although evaporative emissions from residential consumer products or other chemicals may contribute to this factor chemical profile, the strong presence of CO argues that the primary driver of the Factor was combustion processes. The diurnal profile of the Factor showed a much higher daytime contribution than the nighttime contribution, which likely resulted from the dominant northerly wind direction paired with higher traffic activities during the daytime. The diurnal pattern was in contrast with those of the Factors assigned to O&G operations.

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[21] Brown, S. G., Frankel, A., & Hafner, H. R. (2007). Source apportionment of VOCs in the Los Angeles area using positive matrix factorization. Atmospheric Environment, 41(2), 227–237. https://doi.org/10.1016/j.atmosenv.2006.08.021

[22] Watson, J. G., Chow, J. C., & Fujita, E. M. (2001). Review of volatile organic compound source apportionment by chemical mass balance. Atmospheric Environment, 35, 1567–1584. https://doi.org/10.1016/s1352-2310(00)00461-1

Table C.6 Quarterly PMF chemical profiles for Mobile Source Factor 3. Boxes colored in gray indicate chemical compounds not included in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

Mobile Source Factor 3

Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	-	-	0.00E+00	0.0	1.78E-02	7.8
CO	-	-	5.72E+01	36.0	9.09E+01	56.7
ethane	-	-	1.55E+00	9.4	3.91E-01	2.2
propane	-	-	1.06E+00	9.2	1.15E-01	1.1
isobutane	-	-	2.01E-01	5.2	0.00E+00	0.0
n-butane	-	-	4.95E-01	7.7	6.50E-02	1.1
acetylene	-	-	1.99E-01	87.9	1.84E-01	62.2
cyclopentane	-	-	2.91E-02	4.1	3.04E-02	4.3
2-methylbutane	-	-	1.18E-01	3.5	9.42E-02	2.7
n-pentane	-	-	1.27E-01	5.0	3.54E-02	1.3
2,2-dimethylbutane	-	-	1.63E-02	10.0	1.19E-02	7.7
2,3-dimethylbutane	-	-	7.21E-02	16.8	7.63E-02	19.0
2-methylpentane	-	-	6.59E-02	5.8	3.91E-02	3.6
3-methylpentane	-	-	5.00E-02	8.3	2.51E-02	2.8
Isoprene	-	-	-	-	-	-
methylcyclopentane	-	-	1.98E-02	1.0	7.27E-03	0.4
n-hexane	-	-	4.86E-02	3.9	0.00E+00	0.0
benzene	-	-	1.46E-01	35.0	2.56E-01	49.8
cyclohexane	-	-	1.82E-02	2.1	1.73E-02	2.1
2,4-dimethylpentane	-	-	0.00E+00	0.0	5.23E-03	5.0
2,3-dimethylpentane	-	-	0.00E+00	0.0	7.78E-03	2.4
2-methylhexane	-	-	7.14E-03	2.0	1.38E-02	4.4
3-methylhexane	-	-	2.44E-03	0.5	1.54E-02	3.5
methylcyclohexane	-	-	0.00E+00	0.0	0.00E+00	0.0
n-heptane	-	-	2.45E-02	5.1	2.74E-02	6.4
toluene	-	-	8.26E-02	14.6	1.35E-01	22.5
2,2,4-trimethylpentane	-	-	1.17E-02	0.8	2.67E-02	1.8
2,3,4-trimethylpentane	-	-	8.17E-03	9.8	2.03E-02	26.7
2-methylheptane	-	-	0.00E+00	0.0	0.00E+00	0.0
3-methylheptane	-	-	3.08E-03	3.4	4.59E-03	5.8
n-octane	-	-	-	-	3.06E-02	10.0
ethylbenzene	-	-	1.15E-04	0.0	0.00E+00	0.0
m/p-xylene	-	-	1.19E-02	3.9	1.04E-02	3.2
styrene	-	-	-	-	3.43E-03	3.1
o-xylene	-	-	0.00E+00	0.0	0.00E+00	0.0
n-nonane	-	-	0.00E+00	0.0	-	-
n-propylbenzene	-	-	0.00E+00	0.0	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	0.00E+00	0.0
1,3,5-trimethylbenzene	-	-	-	-	-	-
1,2,4-trimethylbenzene	-	-	0.00E+00	0.0	1.97E-03	1.0
1,2,3-trimethylbenzene	-	-	0.00E+00	0.0	0.00E+00	0.0
n-decane	-	-	-	-	-	-
m-diethylbenzene	-	-	7.43E-02	19.0	-	-

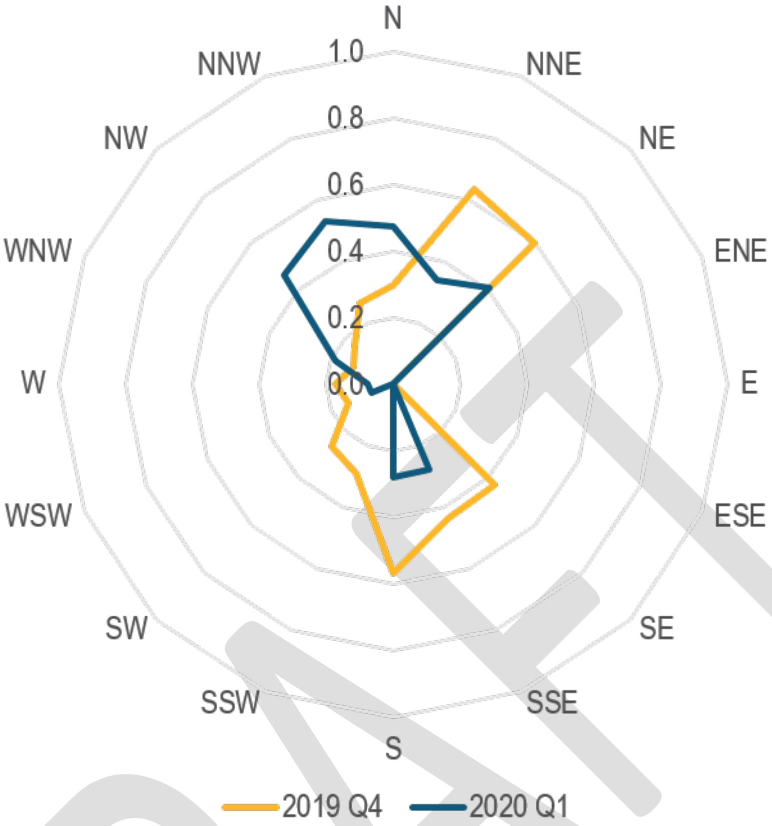

Figure C.20 Quarterly CPF for Mobile Source Factor 3. The wind directions were associated with Factor contributions > 75th percentile.

4. Mobile Source Factor 4 (confidence-level = medium)

Mobile Source Factor 4 was assigned its source category based on contributions from CO, n-propylbenzene, and m-diethylbenzene, with minor influence from BC (see Appendix Table C.7). This Factor was resolved only in 2019 Q4, potentially due to the relatively unique composition of VOC species that passed the QAQC process compared to 2019 Q3 and 2020 Q1. Approximately 25% and 10% of the resolved CO and BC were associated with this Factor, respectively. Although this Factor did not present the most dominant chemical profiles for mobile sources, its association with both n-propylbenzene and m-diethylbenzene suggests that the Factor represented a subset of the emissions profile that describes the mobile sources activities.[23,24] The Factor also included residual influences of ethane and propane that are commonly associated with petroleum-related sources. Although both of these compounds can be emitted from mobile sources, the ratio between ethane and propane for this Factor was 3.94, which suggest that measured air may have been influenced by distribution-ready natural gas or petroleum product of similar composition. However, given its low correlation with ambient CH_4 levels (RSQ = 0.004) and its relatively small contribution of light alkanes, it is unlikely that O&G operations are the dominant influencers of the Factor chemical profile.

The CPF analysis showed that high Factor contributions were generally associated with north-northwesterly winds, consistent with the location of SR 46 and cluster of residential areas like the trailer park with respect to the receptor site (Figure C.21). The diurnal pattern of the Factor shows higher contributions during the daytime, i.e. from 6 AM to 6 PM, indicating that the daytime northerly wind and higher traffic activity during the daytime are the likely influencers of this Factor. O&G operations are significantly less abundant north of Lost Hills.

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[23] Tsai, J. H., Chang, S. Y., & Chiang, H. L. (2012). Volatile organic compounds from the exhaust of light-duty diesel vehicles. *Atmospheric Environment*, *61*, 499-506. https://doi.org/10.1016/j.atmosenv.2012.07.078

[24] Dumanoglu, Y., Kara, M., Altiok, H., Odabasi, M., Elbir, T., & Bayram, A. (2014). Spatial and seasonal variation and source apportionment of volatile organic compounds (VOCs) in a heavily industrialized region. *Atmospheric Environment*, *98*, 168–178. https://doi.org/10.1016/j.atmosenv.2014.08.048

Table C.7 Quarterly PMF chemical profiles for Mobile Source Factor 4. Boxes colored in gray indicate chemical compounds not included in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

Mobile Source Factor 4						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. ($\mu g\ m^{-3}$)	%	Conc. ($\mu g\ m^{-3}$)	%	Conc. ($\mu g\ m^{-3}$)	%
BC	-	-	2.81E-02	9.3	-	-
CO	-	-	4.06E+01	25.5	-	-
ethane	-	-	5.79E-01	3.5	-	-
propane	-	-	1.47E-01	1.3	-	-
isobutane	-	-	1.85E-02	0.5	-	-
n-butane	-	-	7.14E-02	1.1	-	-
Acetylene	-	-	3.94E-03	1.7	-	-
cyclopentane	-	-	1.37E-02	1.9	-	-
2-methylbutane	-	-	8.31E-02	2.4	-	-
n-pentane	-	-	6.26E-02	2.4	-	-
2,2-dimethylbutane	-	-	1.40E-02	8.6	-	-
2,3-dimethylbutane	-	-	2.16E-02	5.0	-	-
2-methylpentane	-	-	0.00E+00	0.0	-	-
3-methylpentane	-	-	0.00E+00	0.0	-	-
Isoprene	-	-	-	-	-	-
methylcyclopentane	-	-	2.19E-03	0.1	-	-
n-hexane	-	-	5.80E-02	4.6	-	-
benzene	-	-	5.22E-02	12.5	-	-
cyclohexane	-	-	3.59E-03	0.4	-	-
2,4-dimethylpentane	-	-	1.34E-02	10.1	-	-
2,3-dimethylpentane	-	-	1.41E-02	4.0	-	-
2-methylhexane	-	-	2.91E-02	8.3	-	-
3-methylhexane	-	-	3.17E-02	6.8	-	-
methylcyclohexane	-	-	0.00E+00	0.0	-	-
n-heptane	-	-	3.76E-02	7.8	-	-
toluene	-	-	1.46E-02	2.6	-	-
2,2,4-trimethylpentane	-	-	2.29E-02	1.5	-	-
2,3,4-trimethylpentane	-	-	6.09E-03	7.3	-	-
2-methylheptane	-	-	6.68E-03	2.6	-	-
3-methylheptane	-	-	1.59E-03	1.8	-	-
n-octane	-	-	-	-	-	-
ethylbenzene	-	-	0.00E+00	0.0	-	-
m/p-xylene	-	-	0.00E+00	0.0	-	-
styrene	-	-	-	-	-	-
o-xylene	-	-	0.00E+00	0.0	-	-
n-nonane	-	-	1.70E-02	10.5	-	-
n-propylbenzene	-	-	2.21E-01	84.6	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	-	-
1,3,5-trimethylbenzene	-	-	-	-	-	-
1,2,4-trimethylbenzene	-	-	1.39E-03	0.7	-	-
1,2,3-trimethylbenzene	-	-	3.18E-02	9.0	-	-
n-decane	-	-	-	-	-	-
m-diethylbenzene	-	-	2.89E-01	73.7	-	-

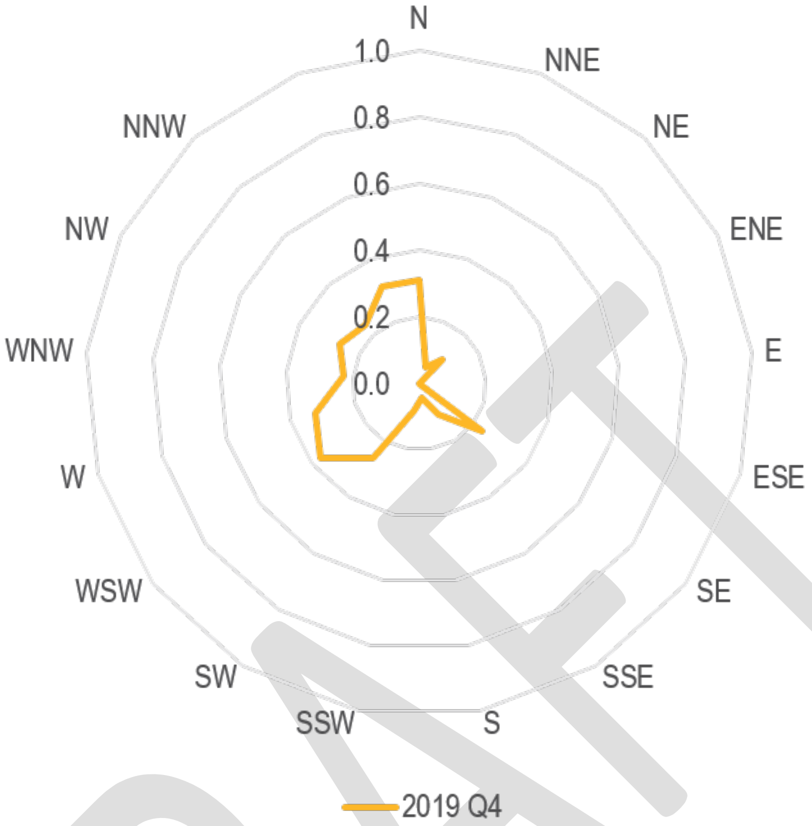

Figure C.21 Quarterly CPF for Mobile Source Factor 4. The wind directions were associated with Factor contributions > 75th percentile.

5. O&G Operation Factor 1 (confidence level = high)

O&G Operation Factor 1 was assigned to the source category based on its abundance of C3-C5 alkanes with relatively higher mass contributions from isomers of butane and pentane, and the notably high percent contributions of cycloalkanes, alkyl cycloalkanes, and 2,2,4-trimethylpentane (see Appendix Table 8). These compounds consistently contributed to over 30% of their respective total masses in each quarter, without considerations for residual errors in the PMF analysis. Variations of this Factor were present in all of the quarterly PMF results with an average RSQ of 0.83 ± 0.09 between each of the resolved chemical profiles. This demonstrated that these Factors represented similar source type(s).

The quarterly PMF analysis at Lost Hills resulted in an average i/n-butane ratio of 0.76 ± 0.17 and an average i/n-pentane ratio of 1.49 ± 0.24. Cross comparison between the Factor chemical profiles and SPECIATE determined that the highest correlated category was petrochemical operations with RSQ > 0.6, i/n-butane ratio of 0.84, and i/n-pentane ratio of 1.74. Ratios of i/n-pentane are typically greater in areas influenced by vehicle tailpipe emissions where urban centers like Los Angeles, CA experiences i/n-pentane of ~2.5.[25] Cyclopentane, cyclohexane, methylcyclopentane, and methylcyclohexane are identified in both emissions from gasoline-based internal combustion engines and evaporation of petroleum fuel products.[26,27] 2,2,4-trimethlypentane on the other hand is typically associated with the petrochemical industry particularly when formulating petroleum fuel products to improve the performance of internal combustion engines. Since PMF did not apportion CO into these Factors, it is unlikely that the Factor represents fuel combustion. These Factors also correlated well with CH_4 (RSQ > 0.25; external to PMF modeling) compared to Factors assigned to the mobile sources (RSQ < 0.04), suggesting that the emissions were co-located with CH_4 emitting sources like O&G operations.

The CPF analysis also associated elevated Factor contributions with southwesterly to westerly winds, consistent with the locations of Lost Hills Oil Field and gas-processing plant (Cahn 3 Gas Plant; Chevron) relative to the receptor site (Figure C.22). The diurnal patterns also demonstrated that the predominant influence of this Factor was during the evening time when the wind preferentially derived from west of Lost Hills.

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[25] Rossabi, S., & Helmig, D. (2018). Changes in atmospheric butanes and pentanes and their isomeric ratios in the continental United States. *Journal of Geophysical Research: Atmospheres*, *123*(7), 3772-3790. https://doi.org/10.1002/2017JD027709

[26] Schauer, J. J., Kleeman, M. J., Cass, G. R., & Simoneit, B. R. (2002). Measurement of emissions from air pollution sources. 5. C1– C32 organic compounds from gasoline-powered motor vehicles. *Environmental science & technology*, *36*(6), 1169-1180. https://doi.org/10.1021/es0108077

[27] U.S. EPA SPECIATE Database. https://www.epa.gov/air-emissions-modeling/speciate

Table C.8 Quarterly PMF chemical profiles for O&G Operations Factor 1. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (µg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 1						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	6.18E-04	0.3	6.37E-03	2.1	0.00E+00	0.0
CO	0.00E+00	0.0	0.00E+00	0.0	0.00E+00	0.0
ethane	0.00E+00	0.0	0.00E+00	0.0	0.00E+00	0.0
propane	0.00E+00	0.0	9.06E-01	7.9	1.08E+00	10.0
isobutane	1.03E+00	31.6	1.40E+00	36.0	1.08E+00	29.2
n-butane	1.51E+00	32.1	1.47E+00	22.7	1.65E+00	26.8
Acetylene	-	-	2.74E-04	0.1	0.00E+00	0.0
cyclopentane	3.07E-01	54.6	3.78E-01	52.8	3.59E-01	51.1
2-methylbutane	1.57E+00	53.1	1.20E+00	34.9	1.18E+00	33.2
n-pentane	1.15E+00	54.9	6.79E-01	26.5	8.79E-01	33.1
2,2-dimethylbutane	3.76E-02	36.4	3.11E-02	19.1	3.87E-02	25.0
2,3-dimethylbutane	9.55E-02	27.0	1.21E-01	28.1	1.05E-01	26.2
2-methylpentane	4.45E-01	54.1	2.70E-01	23.6	3.53E-01	32.5
3-methylpentane	1.42E-01	54.5	9.61E-02	15.9	2.39E-01	26.5
Isoprene	0.00E+00	0.0	-	-	-	-
methylcyclopentane	7.26E-01	55.9	8.68E-01	44.8	6.57E-01	37.2
n-hexane	4.34E-01	51.3	2.08E-01	16.6	2.43E-01	22.2
benzene	3.19E-02	14.8	1.40E-02	3.3	4.46E-02	8.7
cyclohexane	2.54E-01	45.9	4.01E-01	45.2	2.56E-01	31.4
2,4-dimethylpentane	6.49E-02	60.4	5.15E-02	38.6	4.72E-02	45.5
2,3-dimethylpentane	8.67E-02	35.5	1.12E-01	32.0	7.36E-02	23.0
2-methylhexane	7.12E-02	26.4	4.31E-02	12.3	4.82E-02	15.3
3-methylhexane	9.82E-02	26.9	8.08E-02	17.4	8.57E-02	19.6
methylcyclohexane	3.75E-01	37.1	7.98E-01	49.4	5.30E-01	33.5
n-heptane	6.96E-02	18.8	0.00E+00	0.0	2.36E-02	5.5
toluene	2.83E-02	8.2	0.00E+00	0.0	5.85E-02	9.8
2,2,4-trimethylpentane	4.85E-01	46.3	7.46E-01	48.4	5.17E-01	35.1
2,3,4-trimethylpentane	-	-	1.22E-02	14.6	5.83E-04	0.8
2-methylheptane	2.66E-02	17.3	1.94E-02	7.5	0.00E+00	0.0
3-methylheptane	7.28E-03	13.5	2.30E-03	2.6	0.00E+00	0.0
n-octane	4.16E-03	2.5	-	-	1.40E-02	4.6
ethylbenzene	1.54E-02	8.9	9.85E-02	32.2	4.38E-02	14.9
m/p-xylene	-	-	1.43E-02	4.6	2.40E-02	7.4
styrene	-	-	-	-	0.00E+00	0.0
o-xylene	3.35E-03	3.6	2.18E-02	13.8	1.38E-02	8.9
n-nonane	-	-	0.00E+00	0.0	-	-
n-propylbenzene	-	-	1.32E-02	5.0	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	0.00E+00	0.0
1,3,5-trimethylbenzene	0.00E+00	0.0	-	-	-	-
1,2,4-trimethylbenzene	0.00E+00	0.0	3.13E-02	15.0	1.88E-02	9.3
1,2,3-trimethylbenzene	1.41E-03	0.5	6.28E-02	17.8	0.00E+00	0.0
n-decane	0.00E+00	0.0	-	-	-	-
m-diethylbenzene	-	-	0.00E+00	0.0	-	-

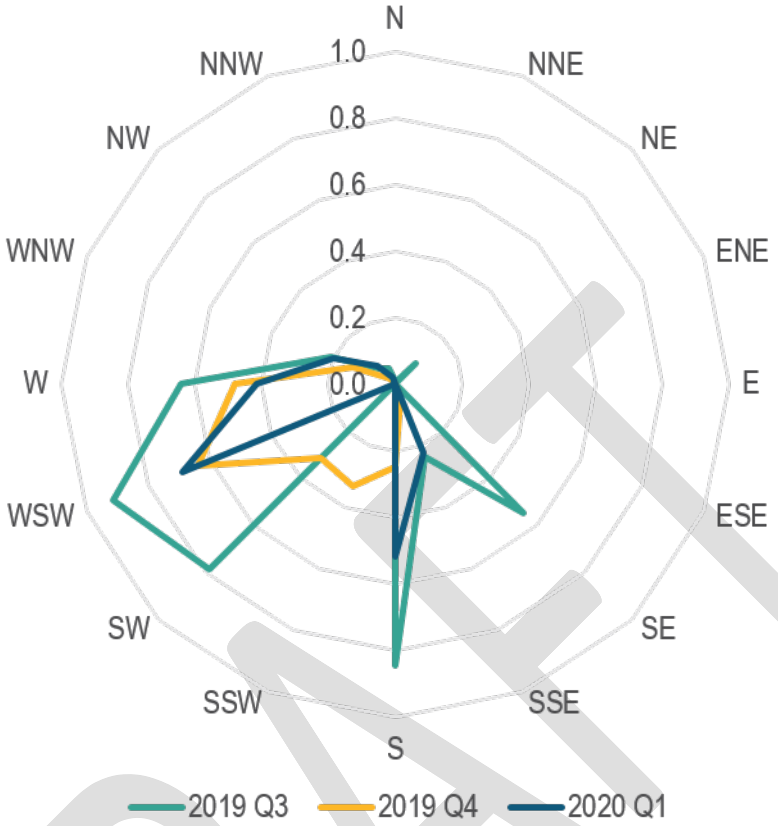

Figure C.22 Quarterly CPF for O&G Operation Factor 1. The wind directions were associated with Factor contributions > 75th percentile.

6. O&G Operation Factor 2 (confidence level = high)

O&G Operation Factor 2 was assigned to this source category based on its dominant signatures of C2-C5 alkanes, including ethane, propane, isobutene, n-butane, isopentane, and n-pentane (see Appendix Table C.9). This Factor was resolved in all three quarters and resulted in RSQ > 0.8 between each of the chemical profiles. Previous studies suggested that natural gas production was the major source of these light alkanes in the South Coast Air Basin in California.[28,29] Correlation analysis using the SPECIATE database determined that O&G source profiles described the Factor chemical profile with RSQ > 0.7. The ratios of i-butane to n-butane and i-pentane to n-pentane were 0.5 – 0.8 and 1.3 – 1.8, respectively. These values were consistent with the respective ratio ranges in the SPECIATE database and literature. In particular, i/n-pentane was significantly lower than the ratio from internal combustion engines, suggesting that the Factor was not associated with the combustion component of the O&G activities (e.g. flaring, off-road engine emissions during oil- and gas-related extraction), although residual influences may still exist. This was further supported by the negligible contribution of BC and CO. The propane to ethane ratio of the factor was 0.6 – 1.0, which was close to the ratio in natural gas composition but substantially larger than the ratio (~0.2) of pipeline quality natural in California.[30,31] This suggested that the Factor may represent the contribution of intermediate petroleum products in addition to distribution-ready fugitive natural gas. However, the specificity of the source types within this source category was not determined. The correlation of these Factors to ambient CH_4 resulted in R of ~0.4 – 0.5. Although the values are low, the Rs were among the highest relative to external CH_4 comparison between all other Factors. This gave confidence that the Factors were generally associated with O&G operations that also emit CH_4 within the region.

The CPF analysis showed that high Factor contributions were associated with southerly and southwesterly winds, consistent with the locations of the O&G facilities with respect to the receptor site (Figure C.23). The diurnal profile of the Factor showed a much lower daytime contribution than the nighttime contribution, which likely resulted from exacerbated

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[28] Peischl, J.; Ryerson, T. B.; Brioude, J.; Aikin, K. C.; Andrews, A. E.; Atlas, E.; Blake, D.; Daube, B. C.; Gouw, J. A. De; Dlugokencky, E.; et al. Quantifying sources of methane using light alkanes in the Los Angeles basin, California. *J. Geophys. Res. Atmos.* 2013, *118*, 4974–4990. https://doi.org/10.1002/jgrd.50413

[29] Warneke, C.; Gouw, J. A. De; Holloway, J. S.; Peischl, J.; Ryerson, T. B.; Atlas, E.; Blake, D.; Trainer, M.; Parrish, D. D. Multiyear trends in volatile organic compounds in Los Angeles , California : Five decades of decreasing emissions. *J. Geophys. Res. Atmos.* 2012, *117* (x), 1–10. https://doi.org/10.1029/2012JD017899

[30] Kirchstetter, T. W.; Singer, B. C.; Harley, R. A.; Kendall, G. R. Impact of Oxygenated Gasoline Use on California Light-Duty Vehicle Emissions. *Environ. Sci. Technol.* 1996, *30* (2), 661–670. https://doi.org/10.1021/es9803714

[31] Faramawy, S.; Zaki, T.; Sakr, A. A. Natural gas origin, composition, and processing : A review. *J. Nat. Gas Sci. Eng.* 2016, *34*, 34–54. https://doi.org/10.1016/j.jngse.2016.06.030

atmospheric mixing during the daytime and changing wind directions. The diurnal pattern was in stark contrast with those of the Factors representing mobile sources (Figure C.12).

Table C.9 Quarterly PMF chemical profiles for O&G Operations Factor 2. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (µg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 2

Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	3.57E-04	0.2	2.20E-03	0.7	0.00E+00	0.0
CO	7.64E-01	0.6	2.37E+00	1.5	0.00E+00	0.0
ethane	4.52E+00	48.0	1.03E+01	62.2	1.34E+01	76.2
propane	4.67E+00	63.8	7.17E+00	62.3	7.80E+00	72.6
isobutane	1.98E+00	60.5	1.98E+00	50.7	2.01E+00	54.3
n-butane	2.35E+00	50.1	3.92E+00	60.5	3.66E+00	59.3
Acetylene	-	-	0.00E+00	0.0	3.97E-03	1.3
cyclopentane	7.93E-02	14.1	2.03E-01	28.3	1.07E-01	15.2
2-methylbutane	6.80E-01	22.9	1.69E+00	49.4	1.62E+00	45.8
n-pentane	3.83E-01	18.2	1.15E+00	45.1	1.26E+00	47.4
2,2-dimethylbutane	6.09E-03	5.9	3.16E-02	19.4	3.48E-02	22.5
2,3-dimethylbutane	2.37E-02	6.7	8.71E-02	20.3	6.41E-02	15.9
2-methylpentane	6.81E-02	8.3	4.05E-01	35.5	3.55E-01	32.7
3-methylpentane	0.00E+00	0.0	1.50E-01	24.8	2.73E-01	30.3
Isoprene	0.00E+00	0.0	-	-	-	-
methylcyclopentane	6.27E-02	4.8	2.85E-01	14.7	5.66E-02	3.2
n-hexane	3.30E-02	3.9	1.71E-01	13.7	1.86E-01	17.0
benzene	4.99E-03	2.3	3.35E-02	8.0	1.80E-02	3.5
cyclohexane	1.61E-02	2.9	1.02E-01	11.5	3.33E-02	4.1
2,4-dimethylpentane	0.00E+00	0.0	1.85E-02	13.9	4.37E-04	0.4
2,3-dimethylpentane	6.91E-04	0.3	2.62E-02	7.5	3.60E-03	1.1
2-methylhexane	0.00E+00	0.0	1.53E-02	4.4	1.61E-02	5.1
3-methylhexane	0.00E+00	0.0	2.63E-02	5.7	2.20E-02	5.0
methylcyclohexane	0.00E+00	0.0	1.44E-01	8.9	0.00E+00	0.0
n-heptane	1.78E-03	0.5	4.82E-02	10.1	4.98E-02	11.6
toluene	0.00E+00	0.0	2.65E-02	4.7	1.52E-02	2.5
2,2,4-trimethylpentane	5.58E-03	0.5	9.36E-02	6.1	0.00E+00	0.0
2,3,4-trimethylpentane	-	-	2.04E-03	2.4	0.00E+00	0.0
2-methylheptane	0.00E+00	0.0	5.39E-03	2.1	2.60E-03	1.2
3-methylheptane	0.00E+00	0.0	1.02E-03	1.1	1.73E-03	2.2
n-octane	0.00E+00	0.0	-	-	2.73E-02	9.0
ethylbenzene	0.00E+00	0.0	0.00E+00	0.0	1.40E-03	0.5
m/p-xylene	-	-	8.95E-03	2.9	1.42E-02	4.3
styrene	-	-	-	-	6.90E-03	6.2
o-xylene	0.00E+00	0.0	2.86E-03	1.8	4.78E-03	3.1
n-nonane	-	-	0.00E+00	0.0	-	-
n-propylbenzene	-	-	1.32E-03	0.5	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	0.00E+00	0.0
1,3,5-trimethylbenzene	0.00E+00	0.0	-	-	-	-
1,2,4-trimethylbenzene	7.13E-04	0.6	8.40E-03	4.0	9.54E-03	4.7
1,2,3-trimethylbenzene	5.31E-03	2.1	1.35E-02	3.8	0.00E+00	0.0
n-decane	0.00E+00	0.0	-	-	-	-
m-diethylbenzene	-	-	0.00E+00	0.0	-	-

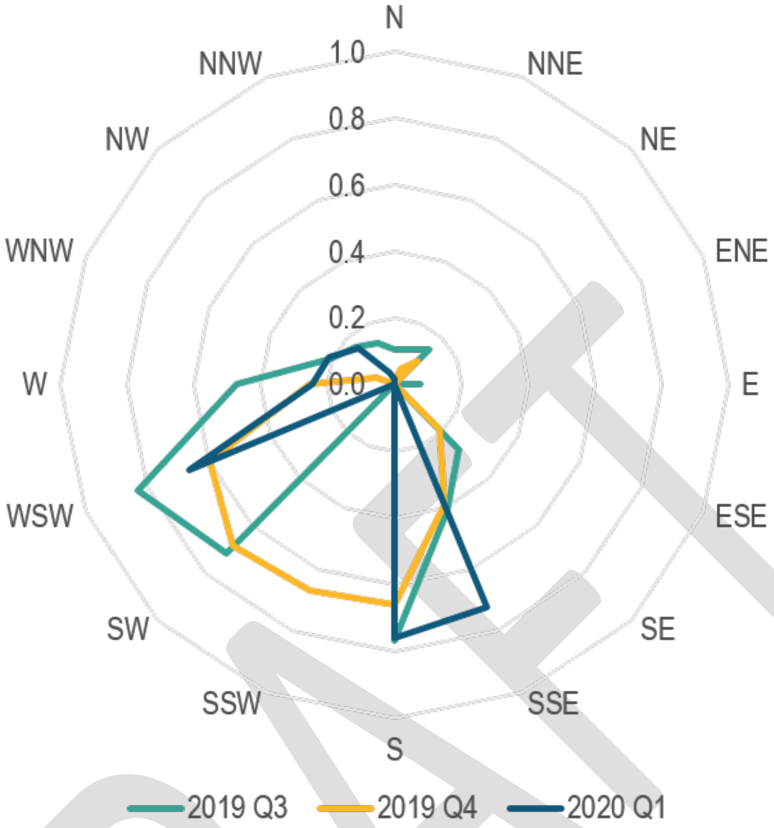

Figure C.23 Quarterly CPF for O&G Operation Factor 2. The wind directions were associated with Factor contributions > 75th percentile.

7. O&G Operation Factor 3 (confidence level = high)

O&G Operation Factor 3 was assigned its source category based on the substantially higher fraction of C6-C8 non-aromatic compounds (~40%), such as n-hexane, n-heptane, and 3-methylheptane (see Appendix Table C.10). The Factor chemical profile had large seasonal variability, with 2019 Q3 closely associated with contributions from ethane and propane. The variability resulted in RSQ ~0.55 among the chemical profiles of the three quarters. Analysis using the SPECIATE database showed that these Factors correlated with the O&G source profiles (RSQ > 0.6), most of which were categorized under O&G production – condensate tanks. Previous near-source measurements indicated that emissions from condensate tanks are relatively depleted in smaller hydrocarbons,[32,33] which is consistent with the chemical profiles having a higher fraction of heavier alkanes. Although the actual O&G emission may not have derived from this specific source type, the similarity in the chemical profile suggests that the Factor represented the contributions from O&G operations. The i-pentane to n-pentane ratio (~0) and propane-to-butane ratio (~3-3.5) were out of the range of the respective ratios from internal engine combustions. In addition, the Factor had a minimal contribution to BC and CO, excluding the possibility that this Factor represented a strong influence from internal combustion sources.

The CPF analysis suggested with high probability that the Factor represented sources to the south or southwest of the receptor site (Figure C.24). Major gas-processing infrastructures are located within a mile southwest of the receptor site, which may be contributing to this Factor. The diurnal profile of the Factor peaks during the night and dips during the day, consistent with other O&G-related Factors identified in this study.

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[32] Warneke, C.; Geiger, F.; Edwards, P. M.; Dube, W.; Pétron, G.; Kofler, J.; Zahn, A.; Brown, S. S. Volatile organic compound emissions from the oil and natural gas industry in the Uintah Basin, Utah : oil- and gas-related well pad emissions compared to ambient air composition. *Atmos. Chem. Phys.* 2014, *14*, 10977–10988. https://doi.org/10.5194/acp-14-10977-2014

[33] Pétron, G.; Frost, G.; Miller, B. R.; Hirsch, A. I.; Montzka, S. A.; Karion, A.; Trainer, M.; Sweeney, C.; Andrews, A. E.; Miller, L.; et al. Hydrocarbon emissions characterization in the Colorado Front Range : A pilot study. *J. Geophys. Res.* 2012, *117*, 1–19. https://doi.org/10.1029/2011JD016360

Table C.10 Quarterly PMF chemical profiles for O&G Operations Factor 3. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 3						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	0.00E+00	0.0	7.27E-03	2.4	6.20E-03	2.7
CO	0.00E+00	0.0	0.00E+00	0.0	9.08E-01	0.6
ethane	3.43E+00	36.5	7.52E-01	4.5	1.61E+00	9.2
propane	2.58E+00	35.3	1.34E+00	11.7	1.01E+00	9.4
isobutane	0.00E+00	0.0	0.00E+00	0.0	0.00E+00	0.0
n-butane	7.32E-01	15.6	3.93E-01	6.1	3.27E-01	5.3
Acetylene	-	-	0.00E+00	0.0	0.00E+00	0.0
cyclopentane	0.00E+00	0.0	0.00E+00	0.0	0.00E+00	0.0
2-methylbutane	3.89E-01	13.1	0.00E+00	0.0	1.60E-01	4.5
n-pentane	3.88E-01	18.5	4.16E-01	16.3	2.34E-01	8.8
2,2-dimethylbutane	5.20E-03	5.0	7.41E-04	0.5	7.33E-03	4.7
2,3-dimethylbutane	1.55E-02	4.4	2.80E-03	0.7	8.76E-03	2.2
2-methylpentane	1.58E-01	19.2	2.58E-01	22.6	1.99E-01	18.3
3-methylpentane	5.89E-02	22.7	2.45E-01	40.5	2.40E-01	26.5
Isoprene	1.14E-03	0.4	-	-	-	-
methylcyclopentane	9.92E-02	7.6	5.62E-01	29.0	5.37E-01	30.3
n-hexane	2.17E-01	25.6	7.28E-01	58.3	5.35E-01	49.0
benzene	1.56E-02	7.3	5.75E-02	13.7	5.64E-02	10.9
cyclohexane	4.78E-02	8.6	2.43E-01	27.4	2.20E-01	27.0
2,4-dimethylpentane	9.58E-03	8.9	4.65E-02	34.9	6.13E-03	5.9
2,3-dimethylpentane	2.22E-02	9.1	6.74E-02	19.2	7.85E-02	24.5
2-methylhexane	6.56E-02	24.3	1.58E-01	45.0	1.39E-01	44.1
3-methylhexane	8.93E-02	24.4	2.05E-01	44.2	1.84E-01	42.1
methylcyclohexane	1.40E-01	13.8	4.23E-01	26.2	4.17E-01	26.4
n-heptane	1.62E-01	43.8	2.94E-01	61.3	2.76E-01	64.6
toluene	6.56E-02	19.1	1.34E-01	23.7	1.53E-01	25.6
2,2,4-trimethylpentane	6.38E-02	6.1	3.93E-01	25.5	3.22E-01	21.9
2,3,4-trimethylpentane	-	-	9.59E-03	11.4	1.15E-02	15.1
2-methylheptane	6.62E-02	43.1	1.70E-01	65.7	1.65E-01	73.6
3-methylheptane	2.00E-02	37.1	5.55E-02	62.0	4.76E-02	60.7
n-octane	2.29E-02	13.9	-	-	0.00E+00	0.0
ethylbenzene	0.00E+00	0.0	3.60E-02	11.8	1.67E-02	5.7
m/p-xylene	-	-	6.86E-02	22.3	3.50E-02	10.7
styrene	-	-	-	-	0.00E+00	0.0
o-xylene	2.96E-03	3.2	2.28E-02	14.4	1.31E-02	8.5
n-nonane	-	-	6.66E-02	41.3	-	-
n-propylbenzene	-	-	9.82E-03	3.8	-	-
m-ethyltoluene	-	-	0.00E+00	0.0	0.00E+00	0.0
1,3,5-trimethylbenzene	1.99E-03	5.1	-	-	-	-
1,2,4-trimethylbenzene	2.59E-03	2.0	1.01E-02	4.8	1.47E-02	7.3
1,2,3-trimethylbenzene	0.00E+00	0.0	0.00E+00	0.0	4.91E-03	2.0
n-decane	2.79E-03	4.3	-	-	-	-
m-diethylbenzene	-	-	0.00E+00	0.0	-	-

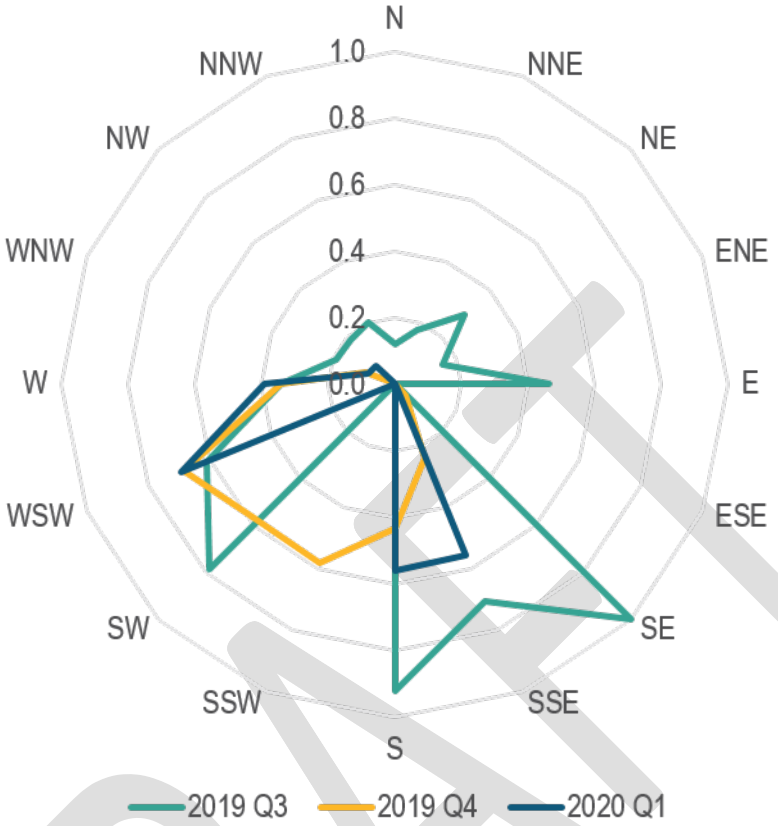

Figure C.24 Quarterly CPF for O&G Operation Factor 3. The wind directions were associated with Factor contributions > 75th percentile.

8. O&G Operation Factor 4 (confidence level = medium)

O&G Operation Factor 4 was assigned its source category based on C2-C9 straight alkanes, branched alkanes, and cycloalkanes along with m-ethyltoluene and 1,2,3-trimethylbenzene (see Appendix Table C.11). The majority of m-ethyltoluene and ~40% of 1,2,3-trimethylbenzene were associated with this Factor. The Factor was resolved in 2019 Q4 and 2020 Q1 with chemical profiles that correlated strongly (RSQ = 0.71). The Factor was similar to the natural gas/crude oil chemical profiles determined by Leuchner & Rappenglück[34] and correlated well with SPECIATE database, particularly with chemical signatures of oil and natural gas production (RSQ > 0.57). The Factor also included 2 – 3% of total CO and BC, suggesting that mobile sources may have had residual influences on this Factor. The Factors had a moderate correlation with ambient CH_4 ambient levels (RSQ ~ 0.13 – 0.16), which were relatively high compared to other Factors not assigned to O&G operations.

The CPF analysis showed that high Factor contributions were associated with westerly and southwesterly winds, consistent with the locations of the O&G facilities with respect to the receptor site (Figure C.25). The diurnal pattern of the Factor showed a much lower daytime contribution than the nighttime contribution, which likely resulted from a combination of exacerbated atmospheric dilution during the daytime and the wind direction that preferentially derived from the west during the nighttime. The diurnal pattern was in stark contrast with those representing mobile sources.

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[34] Leuchner, M., & Rappenglück, B. (2010). VOC source-receptor relationships in Houston during TexAQS-II. *Atmospheric Environment*, *44*(33), 4056–4067. https://doi.org/10.1016/j.atmosenv.2009.02.029

Table C.11 Quarterly PMF chemical profiles for O&G Operations Factor 4. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 4						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	-	-	8.78E-03	2.9	7.42E-03	3.3
CO	-	-	3.77E+00	2.4	2.46E+00	1.5
ethane	-	-	2.76E+00	16.7	8.89E-02	0.5
propane	-	-	3.65E-01	3.2	4.00E-01	3.7
isobutane	-	-	1.54E-01	4.0	2.77E-01	7.5
n-butane	-	-	2.38E-02	0.4	3.41E-01	5.5
Acetylene	-	-	2.32E-02	10.3	3.28E-04	0.1
cyclopentane	-	-	3.32E-02	4.6	0.00E+00	0.0
2-methylbutane	-	-	0.00E+00	0.0	1.52E-01	4.3
n-pentane	-	-	2.03E-02	0.8	1.66E-01	6.2
2,2-dimethylbutane	-	-	1.48E-02	9.1	2.98E-03	1.9
2,3-dimethylbutane	-	-	3.45E-02	8.0	4.64E-03	1.2
2-methylpentane	-	-	8.10E-03	0.7	0.00E+00	0.0
3-methylpentane	-	-	2.83E-02	4.7	0.00E+00	0.0
Isoprene	-	-	-	-	-	-
methylcyclopentane	-	-	1.70E-01	8.8	1.70E-01	9.6
n-hexane	-	-	0.00E+00	0.0	0.00E+00	0.0
benzene	-	-	0.00E+00	0.0	5.99E-03	1.2
cyclohexane	-	-	8.91E-02	10.1	8.00E-02	9.8
2,4-dimethylpentane	-	-	3.51E-03	2.6	4.48E-02	43.2
2,3-dimethylpentane	-	-	5.79E-02	16.5	3.89E-02	12.2
2-methylhexane	-	-	2.72E-02	7.8	2.33E-02	7.4
3-methylhexane	-	-	3.58E-02	7.7	2.91E-02	6.6
methylcyclohexane	-	-	2.19E-01	13.5	2.32E-01	14.7
n-heptane	-	-	1.22E-02	2.5	2.40E-02	5.6
toluene	-	-	5.57E-03	1.0	0.00E+00	0.0
2,2,4-trimethylpentane	-	-	1.80E-01	11.7	1.46E-01	9.9
2,3,4-trimethylpentane	-	-	1.42E-02	17.0	1.57E-02	20.6
2-methylheptane	-	-	3.64E-02	14.0	5.27E-02	23.6
3-methylheptane	-	-	7.39E-03	8.3	1.43E-02	18.2
n-octane	-	-	-	-	2.40E-02	7.9
ethylbenzene	-	-	7.45E-02	24.3	2.98E-02	10.1
m/p-xylene	-	-	3.76E-02	12.2	2.31E-02	7.1
styrene	-	-	-	-	3.70E-02	33.5
o-xylene	-	-	3.30E-02	20.8	1.54E-02	9.9
n-nonane	-	-	3.32E-02	20.6	-	-
n-propylbenzene	-	-	1.01E-02	3.9	-	-
m-ethyltoluene	-	-	1.27E-01	100.0	1.20E-01	88.1
1,3,5-trimethylbenzene	-	-	-	-	-	-
1,2,4-trimethylbenzene	-	-	5.14E-02	24.7	1.99E-02	9.8
1,2,3-trimethylbenzene	-	-	1.28E-01	36.4	8.86E-02	35.6
n-decane	-	-	-	-	-	-
m-diethylbenzene	-	-	0.00E+00	0.0	-	-

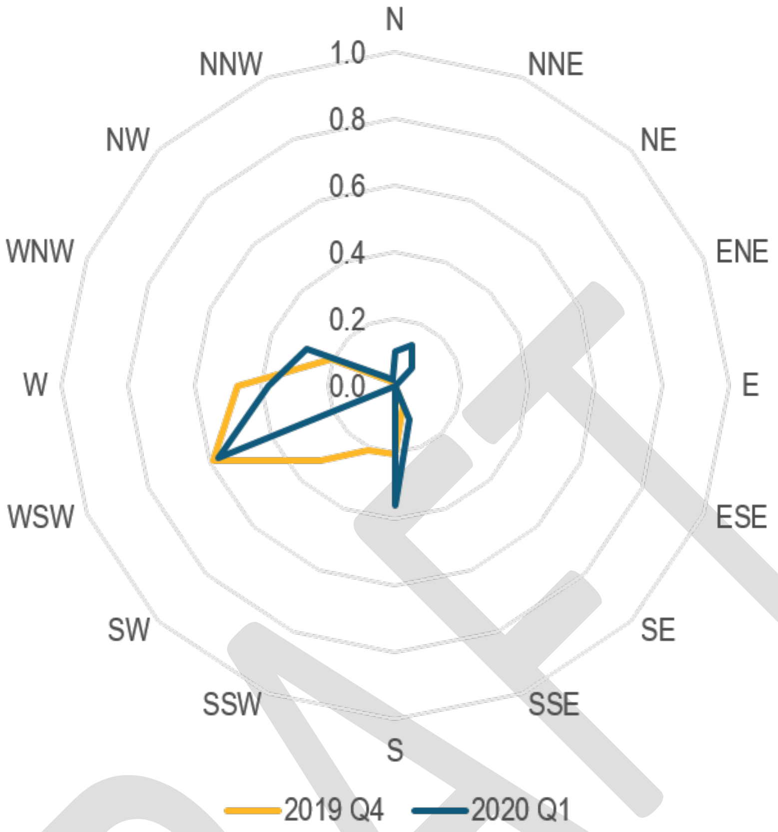

Figure C.25 Quarterly CPF for O&G Operation Factor 4. The wind directions were associated with Factor contributions > 75th percentile.

9. O&G Operation Factor 5 (confidence level = medium)

O&G Operation Factor 5 was assigned to its source category based on C8-C10 compounds (ethylbenzene, o-xylene, isomers of trimethylbenzenes, and n-decane) that accounted for over half of the total mass, respectively (see Appendix Table C.12). This Factor was resolved only in 2019 Q3. These compounds exist in both crude oil and vehicular emissions[35,36] although correlation analysis using the SPECIATE database showed that the Factor profile was highly correlated with O&G source profiles (RSQ > 0.5), most of which were identified as O&G wells. Although the actual O&G emission may not have derived from this specific source type, the similarity in the chemical profile suggests that the Factor represented the contributions from O&G operations. The Factor had a negligible contribution to BC and CO, making this Factor less associated with mobile source emissions (particularly from combustion).

The CPF analysis suggested with high probability that the Factor represented air mass that derived from the south or southwest of the receptor site, consistent with the location of O&G infrastructure and the Lost Hills Oil Field (Figure C.26). The diurnal pattern of the Factor peaked during the night and dropped during the day, consistent with other Factors assigned to O&G operations.

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[35] Fraser, M. P., Cass, G. R., and Simoneit, B. R. T. Gas-Phase and Particle phase Organic Compounds Emitted from Motor Vehicle Traffic in a Los Angeles Roadway Tunnel. *Environ. Sci. Technol.* **1998**, *32*, 2051–2060. https://doi.org/10.1021/es970916e

[36] D'Auria, M.; Emanuele, L.; Racioppi, R.; Velluzzi, V. Photochemical degradation of crude oil : Comparison between direct irradiation , photocatalysis , and photocatalysis on zeolite. *J. Hazard. Mater.* **2009**, *164*, 32–38. https://doi.org/10.1016/j.jhazmat.2008.07.111

Table C.12 Quarterly PMF chemical profiles for O&G Operations Factor 5. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (µg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 5						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (µg m^{-3})	%	Conc. (µg m^{-3})	%	Conc. (µg m^{-3})	%
BC	0.00E+00	0.0	-	-	-	-
CO	0.00E+00	0.0	-	-	-	-
ethane	2.10E-01	2.2	-	-	-	-
propane	0.00E+00	0.0	-	-	-	-
isobutane	1.70E-01	5.2	-	-	-	-
n-butane	0.00E+00	0.0	-	-	-	-
Acetylene	-	-	-	-	-	-
cyclopentane	9.80E-02	17.4	-	-	-	-
2-methylbutane	0.00E+00	0.0	-	-	-	-
n-pentane	1.37E-02	0.7	-	-	-	-
2,2-dimethylbutane	1.07E-02	10.3	-	-	-	-
2,3-dimethylbutane	2.70E-02	7.7	-	-	-	-
2-methylpentane	4.65E-02	5.7	-	-	-	-
3-methylpentane	0.00E+00	0.0	-	-	-	-
Isoprene	1.32E-03	0.5	-	-	-	-
methylcyclopentane	3.76E-01	28.9	-	-	-	-
n-hexane	1.27E-01	15.0	-	-	-	-
benzene	3.03E-02	14.1	-	-	-	-
cyclohexane	1.93E-01	34.8	-	-	-	-
2,4-dimethylpentane	1.91E-02	17.8	-	-	-	-
2,3-dimethylpentane	8.59E-02	35.2	-	-	-	-
2-methylhexane	7.33E-02	27.2	-	-	-	-
3-methylhexane	8.21E-02	22.5	-	-	-	-
methylcyclohexane	4.71E-01	46.6	-	-	-	-
n-heptane	5.89E-02	15.9	-	-	-	-
toluene	7.92E-02	23.0	-	-	-	-
2,2,4-trimethylpentane	4.16E-01	39.6	-	-	-	-
2,3,4-trimethylpentane	-	-	-	-	-	-
2-methylheptane	5.59E-02	36.3	-	-	-	-
3-methylheptane	1.53E-02	28.5	-	-	-	-
n-octane	5.76E-02	34.9	-	-	-	-
ethylbenzene	1.20E-01	69.0	-	-	-	-
m/p-xylene	-	-	-	-	-	-
styrene	-	-	-	-	-	-
o-xylene	5.45E-02	58.5	-	-	-	-
n-nonane	-	-	-	-	-	-
n-propylbenzene	-	-	-	-	-	-
m-ethyltoluene	-	-	-	-	-	-
1,3,5-trimethylbenzene	2.20E-02	56.3	-	-	-	-
1,2,4-trimethylbenzene	6.99E-02	53.9	-	-	-	-
1,2,3-trimethylbenzene	1.16E-01	45.0	-	-	-	-
n-decane	3.34E-02	51.0	-	-	-	-
m-diethylbenzene	-	-	-	-	-	-

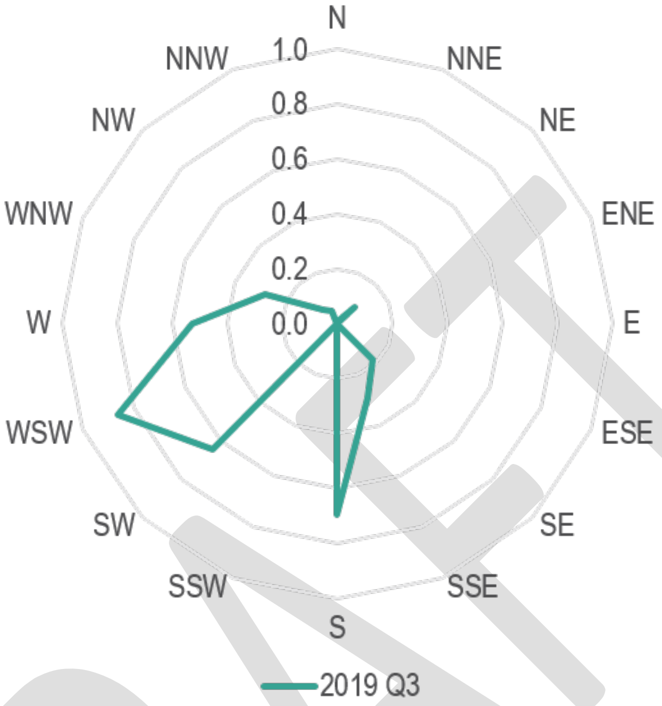

Figure C.26 Quarterly CPF for O&G Operation Factor 5. The wind directions were associated with Factor contributions > 75th percentile.

10. O&G Operation Factor 6 (confidence level = low)

O&G Operation Factor 6 was assigned to its source category based on contributions from over 40% of the total n-octane, ethylbenzene, styrene, and 1,2,3-trimethylbenzene measured during the study, with relatively smaller influences from CO, 2,2(3)-dimethylbutane, and cyclic alkanes (see Appendix Table C.13). This Factor was resolved only in 2020 Q1 but resembled a subcomponent of Mobile Source Factor 2 chemical profile for 2019 Q3. In particular, the resemblance was with contributions of n-octane, 2,2(3)-dimethylbutane, 1,2,3(4)-trimethylbenzene, and the lack of dominant benzene and toluene signatures. Unlike Mobile Source Factor 2, this Factor included ethylbenzene and styrene as the prominent contributors while having residual contributions from CO and BC. Styrene is a widely used industrial chemical that is produced by the dehydrogenation of ethylbenzene.[37] Although a majority of these chemicals are emitted from mobile sources and are used as markers for tailpipe emissions, the combination of n-octane and styrene also suggests that the Factor was heavily influenced by petroleum fuel products and industrial processes.[38,39,40] Correlation with SPECIATE database suggested that the Factor resembled the chemical profiles of O&G production (RSQ >0.8). Based on the minor contribution of CO, BC, and acetylene in this Factor, it is plausible that mobile sources or other fuel combustion sources had influenced the results. Since this Factor is reported under the O&G category, such caveats should be used in further discussions.

The CPF analysis showed that high Factor contributions were associated with westerly winds, consistent with the location of Lost Hills Oil Field with respect to the receptor site (Figure C.27). The diurnal pattern of the Factor peaked during the night and dropped during the day, consistent with other Factors assigned to O&G operations.

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[37] Tang, W.; Hemm, I.; Eisenbrand, G. Estimation of human exposure to styrene and ethylbenzene. *Toxicology* **2000**, *144*, 39–50. https://doi.org/10.1016/S0300-483X(99)00188-2

[38] Brown, S. G., Frankel, A., & Hafner, H. R. (2007). Source apportionment of VOCs in the Los Angeles area using positive matrix factorization. *Atmospheric Environment*, *41*(2), 227–237. https://doi.org/10.1016/j.atmosenv.2006.08.021

[39] Guha, A., Gentner, D. R., Weber, R. J., Provencal, R., & Goldstein, A. H. (2015). Source apportionment of methane and nitrous oxide in California's San Joaquin Valley at CalNex 2010 via positive matrix factorization. *Atmospheric Chemistry and Physics*, *15*(20), 12043–12063. https://doi.org/10.5194/acp-15-12043-2015

[40] Leuchner, M., & Rappenglück, B. (2010). VOC source-receptor relationships in Houston during TexAQS-II. *Atmospheric Environment*, *44*(33), 4056–4067. https://doi.org/10.1016/j.atmosenv.2009.02.029

Table C.13 Quarterly PMF chemical profiles for O&G Operations Factor 6. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

O&G Operation Factor 6						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	-	-	-	-	6.35E-03	2.8
CO	-	-	-	-	1.32E+01	8.2
ethane	-	-	-	-	2.09E+00	11.9
propane	-	-	-	-	0.00E+00	0.0
isobutane	-	-	-	-	3.05E-01	8.2
n-butane	-	-	-	-	0.00E+00	0.0
Acetylene	-	-	-	-	3.47E-02	11.7
cyclopentane	-	-	-	-	1.70E-01	24.2
2-methylbutane	-	-	-	-	1.77E-01	5.0
n-pentane	-	-	-	-	8.24E-02	3.1
2,2-dimethylbutane	-	-	-	-	3.21E-02	20.7
2,3-dimethylbutane	-	-	-	-	8.45E-02	21.0
2-methylpentane	-	-	-	-	6.69E-02	6.2
3-methylpentane	-	-	-	-	8.02E-02	8.9
Isoprene	-	-	-	-	-	-
methylcyclopentane	-	-	-	-	3.14E-01	17.8
n-hexane	-	-	-	-	7.89E-02	7.2
benzene	-	-	-	-	2.52E-02	4.9
cyclohexane	-	-	-	-	1.98E-01	24.2
2,4-dimethylpentane	-	-	-	-	0.00E+00	0.0
2,3-dimethylpentane	-	-	-	-	9.36E-02	29.3
2-methylhexane	-	-	-	-	3.54E-02	11.2
3-methylhexane	-	-	-	-	6.18E-02	14.1
methylcyclohexane	-	-	-	-	4.02E-01	25.4
n-heptane	-	-	-	-	0.00E+00	0.0
toluene	-	-	-	-	0.00E+00	0.0
2,2,4-trimethylpentane	-	-	-	-	4.18E-01	28.4
2,3,4-trimethylpentane	-	-	-	-	1.19E-02	15.6
2-methylheptane	-	-	-	-	3.79E-03	1.7
3-methylheptane	-	-	-	-	0.00E+00	0.0
n-octane	-	-	-	-	2.09E-01	68.5
ethylbenzene	-	-	-	-	1.22E-01	41.3
m/p-xylene	-	-	-	-	3.09E-02	9.5
styrene	-	-	-	-	5.80E-02	52.5
o-xylene	-	-	-	-	3.12E-02	20.2
n-nonane	-	-	-	-	-	-
n-propylbenzene	-	-	-	-	-	-
m-ethyltoluene	-	-	-	-	0.00E+00	0.0
1,3,5-trimethylbenzene	-	-	-	-	-	-
1,2,4-trimethylbenzene	-	-	-	-	5.56E-02	27.5
1,2,3-trimethylbenzene	-	-	-	-	1.14E-01	46.0
n-decane	-	-	-	-	-	-
m-diethylbenzene	-	-	-	-	-	-

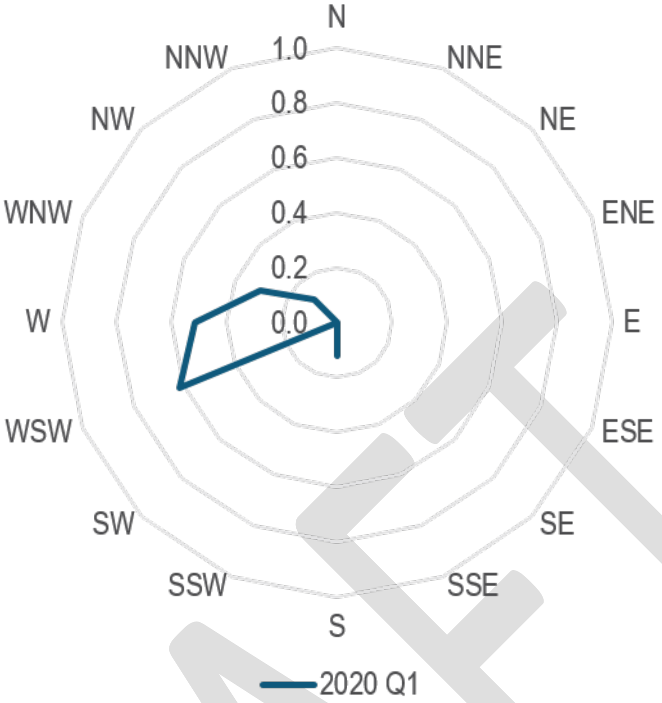

Figure C.27 Quarterly CPF for O&G Operation Factor 6. The wind directions were associated with Factor contributions > 75th percentile.

11. Biogenic Factor 1 (confidence level = medium)

Biogenic Factor 1 was assigned to its source category based on the isoprene signature that dominated the hydrocarbon concentration in the Factor chemical profile (96% of total measured isoprene) (see Appendix Table C.14). Isoprene is typically used as a tracer for biogenic emissions.[41, 42] The Factor was resolved only in 2019 Q3, when summertime conditions exacerbated the biogenic emissions. It is possible that the Factor represented a mix of biogenic emissions, mobile source emissions, and biomass burning emissions based on the apportionment of 6% and 13% of total measured BC and CO, respectively.

The CPF analysis showed that high Factor contributions were associated with the westerly winds, suggesting that the Factor may represent emissions from the forests on the west coast that were mixed with regional or local air pollutant emission sources during the transport (Figure C.28). The diurnal profile of this Factor showed a relatively lower contribution during daytime compared to nighttime, which was likely caused by deep atmospheric mixing during the sunlit hours and the time lag during atmospheric transport.

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[41] Harley, P. C.; Lerdau, M. T. Ecological and evolutionary aspects of isoprene emission from plants. Oecologia 1999, 118, 109–123. https://doi.org/10.1007/s004420050709

[42] Guenther, A. B.; Jiang, X.; Heald, C. L.; Sakulyanontvittaya, T.; Duhl, T.; Emmons, L. K.; Wang, X. Model Development The Model of Emissions of Gases and Aerosols from Nature version 2 . 1 (MEGAN2 . 1): an extended and updated framework for modeling biogenic emissions. Geosci. Model D 2012, 5, 1471–1492. https://doi.org/10.5194/gmd-5-1471-2012

Table C.14 Quarterly PMF chemical profiles for Biogenic Factor 1. Boxes colored in gray indicate chemical compounds not resulted in the PMF analysis. Conc. (μg m^{-3}) pertains to the concentration of species and % pertains to the percent of species apportioned to the respective Factors in each quarterly PMF analysis.

Biogenic Factor 1						
Species	2019 Q3		2019 Q4		2020 Q1	
	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%	Conc. (μg m^{-3})	%
BC	1.22E-02	6.5	-	-	-	-
CO	1.52E+01	12.8	-	-	-	-
ethane	5.59E-02	0.6	-	-	-	-
propane	0.00E+00	0.0	-	-	-	-
isobutane	2.37E-02	0.7	-	-	-	-
n-butane	2.66E-02	0.6	-	-	-	-
Acetylene	-	-	-	-	-	-
cyclopentane	5.32E-03	0.9	-	-	-	-
2-methylbutane	2.20E-02	0.7	-	-	-	-
n-pentane	1.59E-02	0.8	-	-	-	-
2,2-dimethylbutane	6.92E-04	0.7	-	-	-	-
2,3-dimethylbutane	1.73E-02	4.9	-	-	-	-
2-methylpentane	6.20E-03	0.8	-	-	-	-
3-methylpentane	3.82E-03	1.5	-	-	-	-
Isoprene	2.76E-01	96.3	-	-	-	-
methylcyclopentane	7.68E-03	0.6	-	-	-	-
n-hexane	0.00E+00	0.0	-	-	-	-
benzene	5.92E-03	2.8	-	-	-	-
cyclohexane	4.50E-03	0.8	-	-	-	-
2,4-dimethylpentane	2.48E-03	2.3	-	-	-	-
2,3-dimethylpentane	3.69E-04	0.2	-	-	-	-
2-methylhexane	1.28E-03	0.5	-	-	-	-
3-methylhexane	5.27E-03	1.4	-	-	-	-
methylcyclohexane	8.91E-03	0.9	-	-	-	-
n-heptane	8.33E-03	2.3	-	-	-	-
toluene	0.00E+00	0.0	-	-	-	-
2,2,4-trimethylpentane	1.09E-02	1.0	-	-	-	-
2,3,4-trimethylpentane	-	-	-	-	-	-
2-methylheptane	0.00E+00	0.0	-	-	-	-
3-methylheptane	1.68E-03	3.1	-	-	-	-
n-octane	9.80E-03	5.9	-	-	-	-
ethylbenzene	8.66E-04	0.5	-	-	-	-
m/p-xylene	-	-	-	-	-	-
styrene	-	-	-	-	-	-
o-xylene	0.00E+00	0.0	-	-	-	-
n-nonane	-	-	-	-	-	-
n-propylbenzene	-	-	-	-	-	-
m-ethyltoluene	-	-	-	-	-	-
1,3,5-trimethylbenzene	1.02E-03	2.6	-	-	-	-
1,2,4-trimethylbenzene	3.32E-03	2.6	-	-	-	-
1,2,3-trimethylbenzene	1.11E-02	4.3	-	-	-	-
n-decane	2.00E-03	3.1	-	-	-	-
m-diethylbenzene	-	-	-	-	-	-

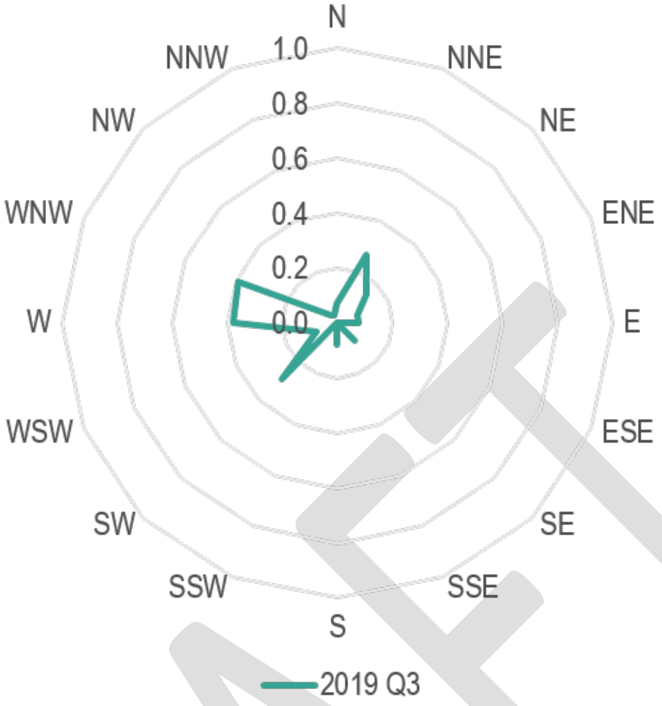

Figure C.28 Quarterly CPF for Biogenic Factor 1. The wind directions were associated with Factor contributions > 75th percentile.

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D. Additional Comparisons to Well Drilling, Stimulation, and Workover Events

Beyond the information presented in Section 3.5, staff further compared SNAPS data to well drilling, stimulation, and workover events in an effort to determine if there was a direct association between number of events, seasonality, type of event, and pollutant concentrations measured in Lost Hills (Figures D.1-D.4).

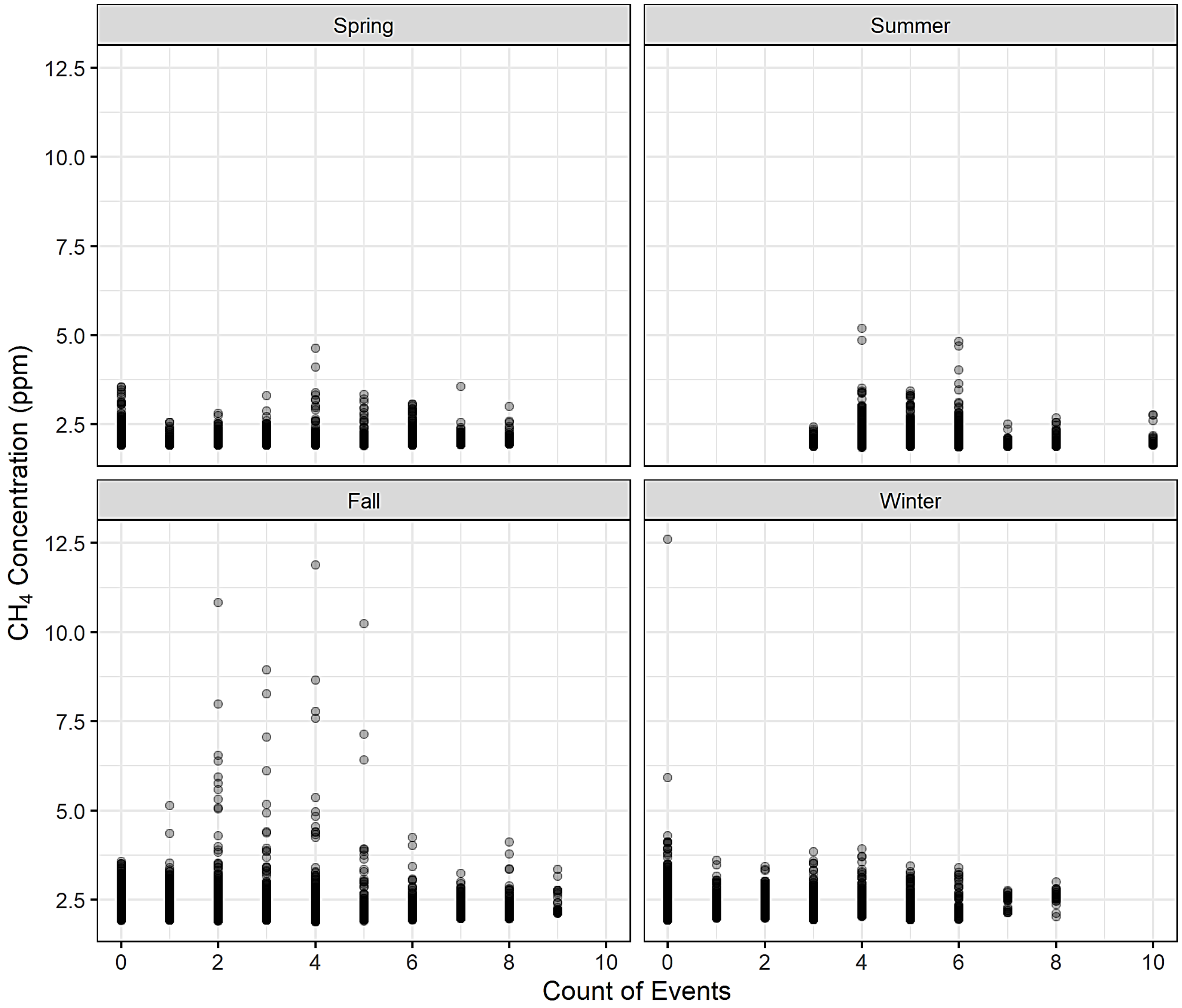
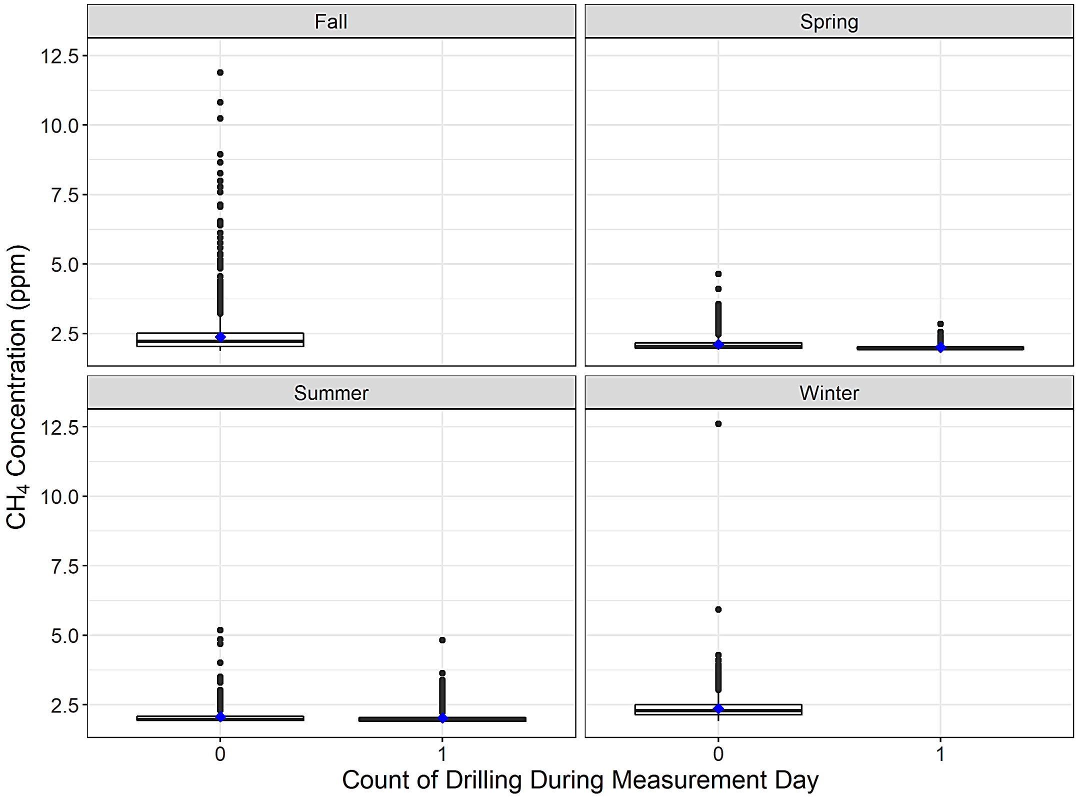
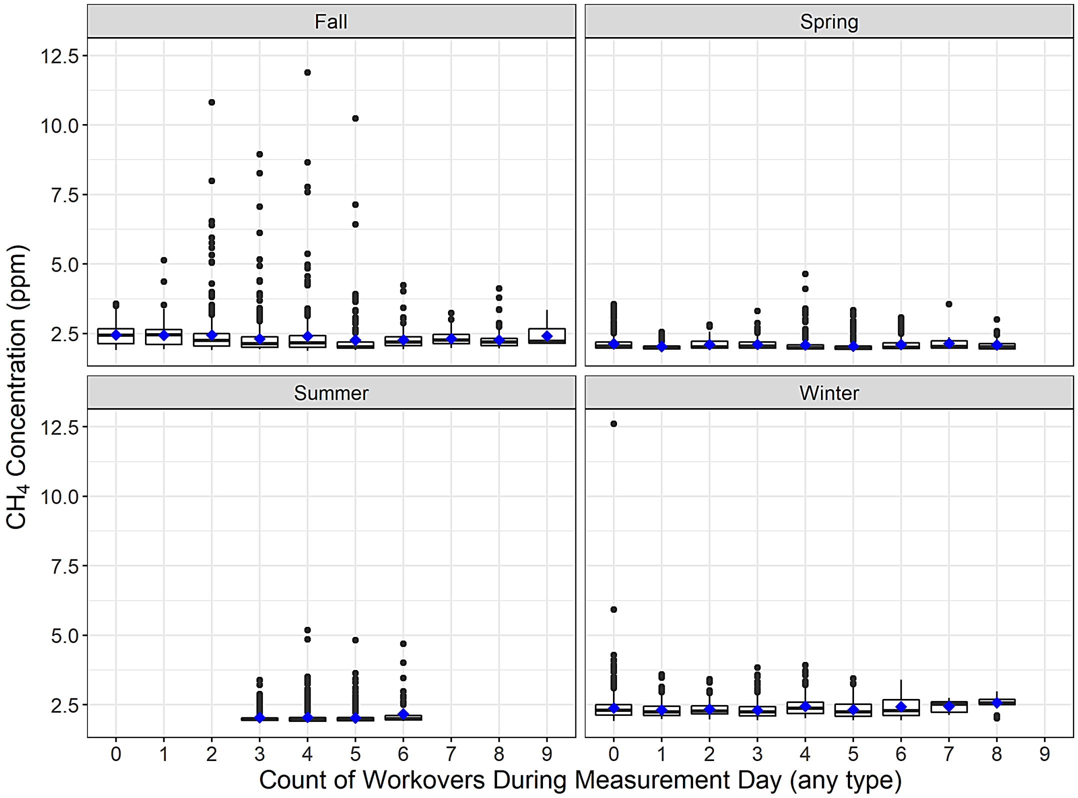


Figure D.1 Number of simultaneous operator events vs. methane concentration observed, separated by season (spring, summer, fall, and winter).

CH_4 Concentration Distributions by Number of Wells Being Drilled on Measurement Day



CH_4 Concentration Distributions by Number of Workovers on Measurement Day



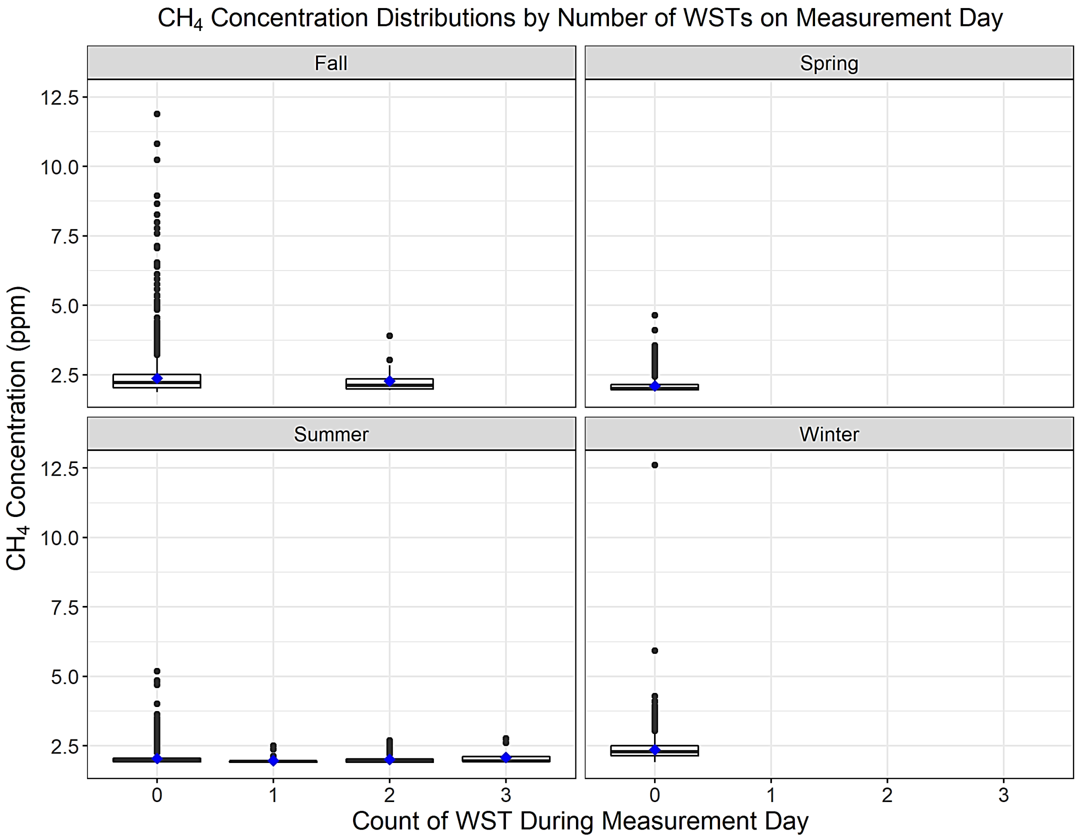


Figure D.2 Total number of drilling (top), workover (middle), and well stimulation (bottom) events vs methane concentration at the SNAPS trailer, separated by season. The numbers below each box are the count of hourly data points falling in that category.

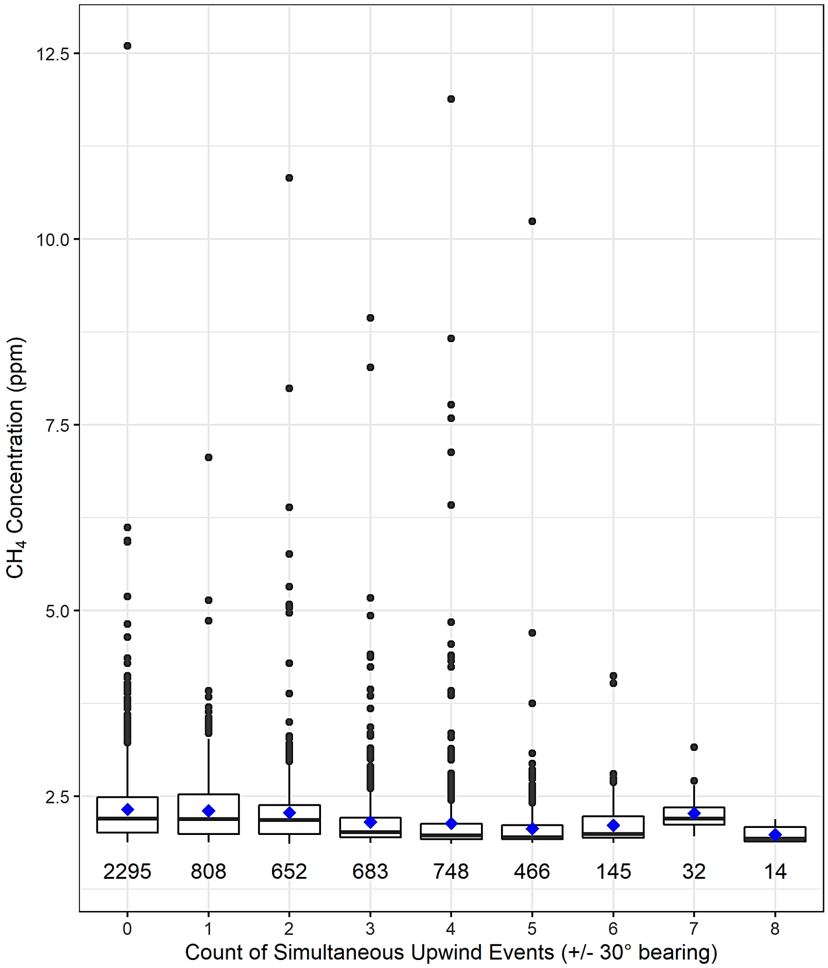


Figure D.3 Methane concentration distribution by number of simultaneous upwind events. Blue dots are average (mean) concentrations and numbers below each box are the count of hourly data points in that column.

Staff created a single indicator meant to capture both the distance and number of events. This indicator uses inverse-squared distance weighting to account for how many and how close the events were to the SNAPS trailer, as in the equation below. Higher values represent more and closer events.

$$\text{Inverse distance weighted score} = \sum_{i=1}^{n} \frac{1}{d_i^2}$$

Where:

d_i = distance of event i from SNAPS trailer

n = number of events occuring on measurement day

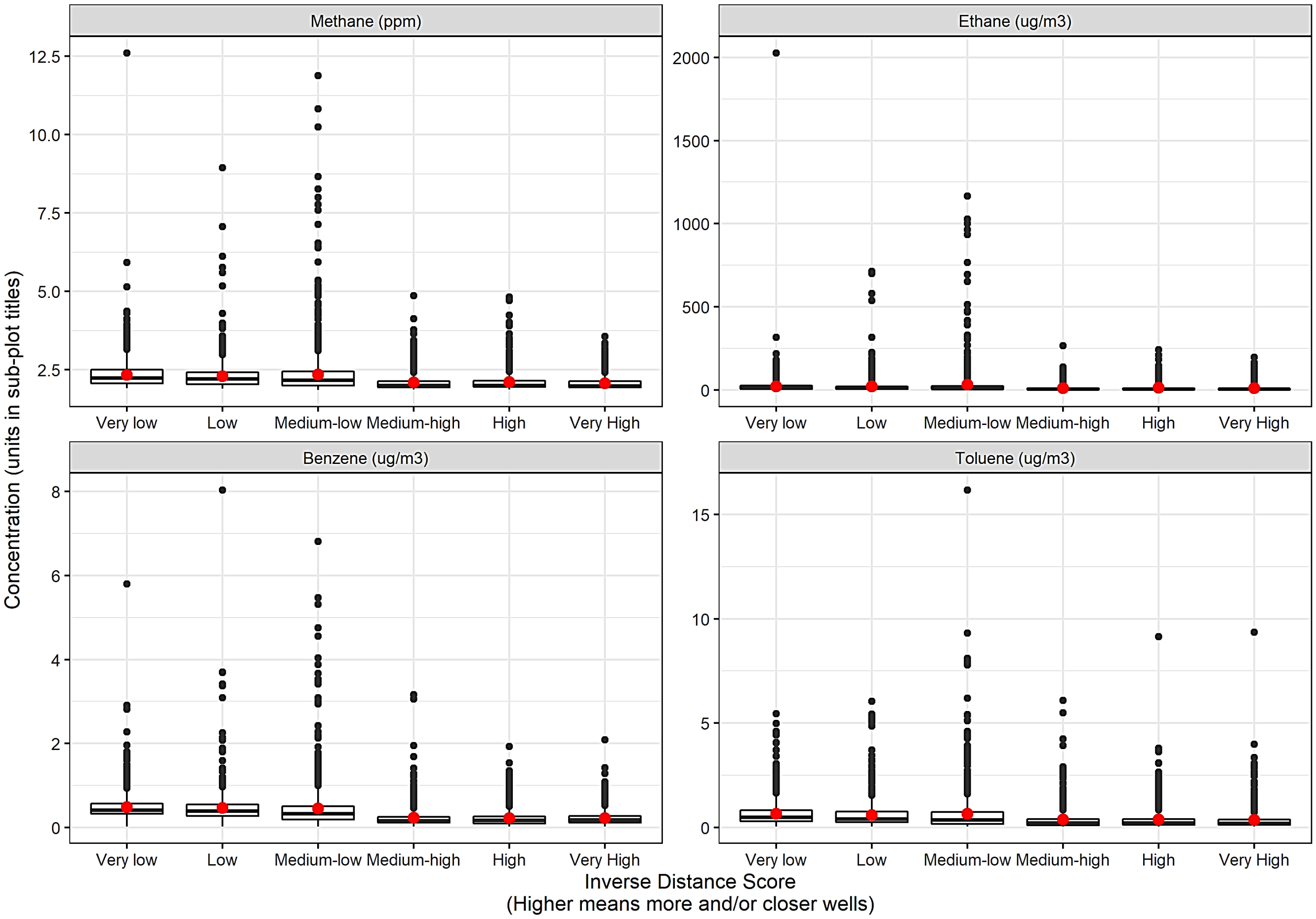


Figure D.4 Inverse distance weighted event score vs. concentrations of methane, ethane, benzene, and toluene. The x axis is binned based on an equal number of data points per bin, ranked from very low to very high. Higher values on the x axis represent more and closer events. The red circles represent the mean while the horizontal lines within the boxes represent the median.

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E. Additional Mobile Monitoring Analysis

Staff found good agreement in methane between the instrument on the mobile monitoring platform and the trailer when the platform is monitoring within 150 m of the trailer (Figure E.1). The RMS error (relative to the trailer) was less than 0.1 ppm for both the Aeris and the Picarro instruments. Differences likely arose from differences in the inlet, instrument design, and instrument precision.

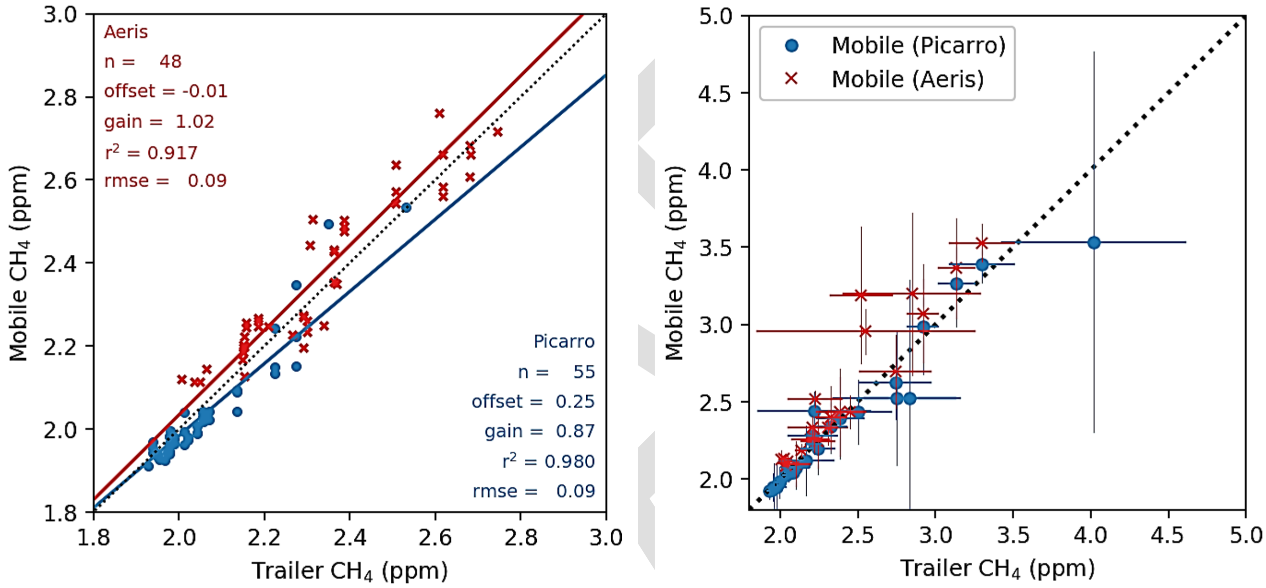

Figure E.1 Comparison of the Aeris MIRA PICO Mobile LDS (red) and Picarro 2204 (blue) methane from the mobile platform relative to the Picarro 2401 methane at the trailer site. (left) Data shown are 10-minute averages when the mobile platform is located within 150 m of the trailer. (right) Data shown are 1-hour averages when the mobile platform is located within Lost Hills (1 sq. mile region). Error bars indicate the 2 standard deviation variability on the 1-hour average concentration.

Staff also explored for any systematic differences in methane concentrations depending on whether the mobile platform was upwind or downwind of the Lost Hills Oil Field. Staff used the simple criteria of whether the wind was non-zero and from south to northwest direction to determine if the trailer was downwind of the oilfield. The mobile data used below only included measurements made within approximately 4 sq. miles around Lost Hills, using the same criteria for the mobile platform as the trailer (Figure E.2).

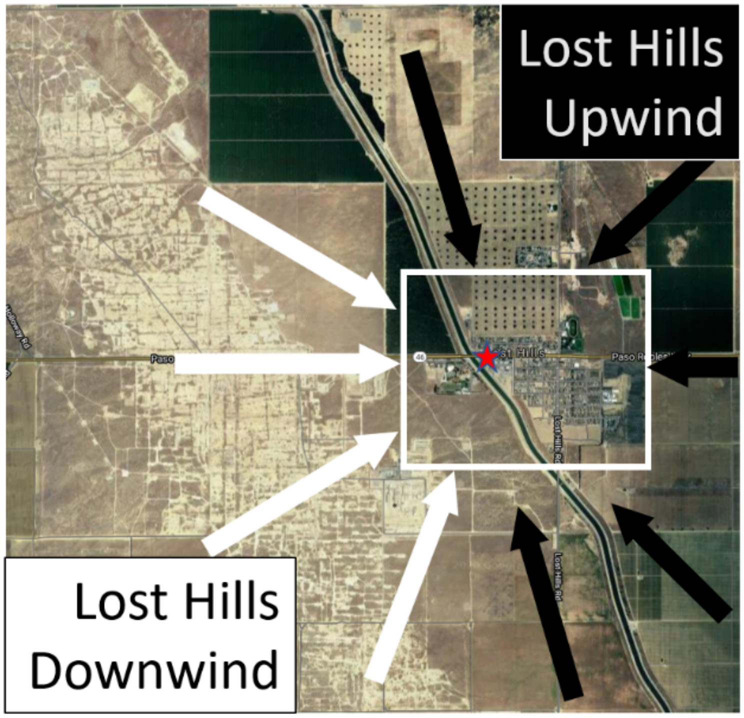

Figure E.2 Schematic of the region included for mobile monitoring analysis (box) and the wind direction for which the mobile platform and trailer (star) are considered to be upwind (black rightmost four arrows) and downwind (white leftmost four arrows) of oil and gas-related operations.

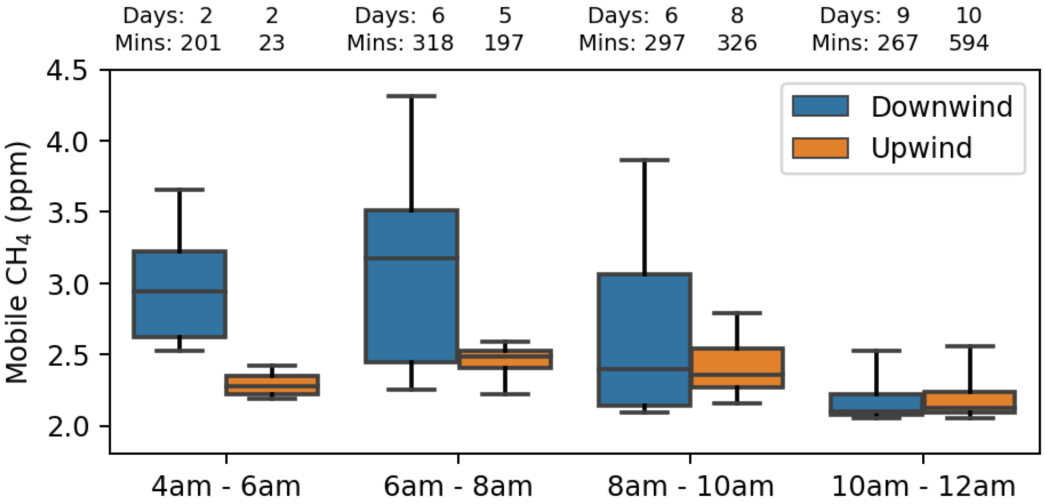

Figure E.3 All mobile monitoring data grouped by whether the mobile platform was downwind or upwind of oil and gas-related operations, and for different times of day. Boxes show the 25th and 75th percentiles and whiskers indicate the 5th and 95th percentiles of the methane concentration. The horizontal lines within the boxes represent the median (50th *percentile). The number of different days and the number of minutes of data in each box plot are listed at the top of the figure.*

Figure E.3 summarizes the mobile monitoring methane measurements in Lost Hills between July 2019 and January 2020, grouped by wind direction and time of day. There was a clear bias to higher methane concentrations when the platform was considered downwind of oil and gas-related operations. This difference was more pronounced earlier in the morning, greatly reduced by 8 am (although downwind concentrations were more variable) and was not present after 10 am. There were 50% fewer minutes of data available before 8 am when the platform was upwind, rather than downwind; therefore, this may contribute to the reduced variability.

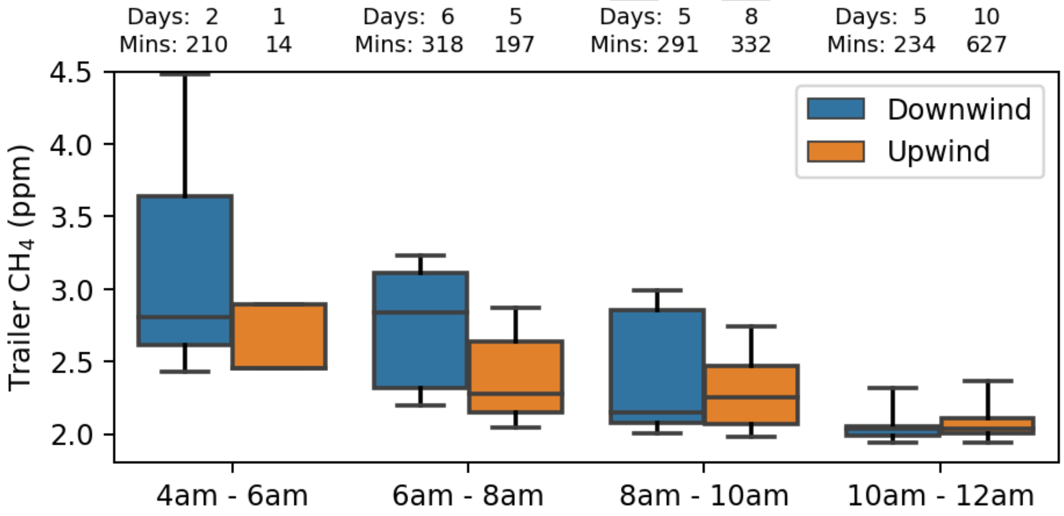

Figure E.4 The same as Figure E.3 but for the trailer methane measurements taken while mobile monitoring was undertaken. Data is grouped by whether the trailer is downwind or upwind of oil and gas-related operations, and for different times of day. Boxes show the 25th and 75th percentiles and whiskers indicate the 5th and 95th percentiles of the CH_4 concentration. The horizontal lines within the boxes represent the median (50th percentile). The number of different days and the number of minutes of data in each box plot are listed at the top of the figure.

The trailer presented a similar picture when sampled at the time of mobile monitoring and following the same criteria for upwind or downwind classification (Figure E.4). However, when the full campaign of data was used (over 11 months), the upwind and downwind differences were not clearly different (Figure E.5). The early morning still showed higher concentrations than later in the day but the upwind and downwind distribution of methane were indistinguishable. This may indicate that the upwind and downwind differences in the mobile monitoring data were dependent upon the specific condition on those days rather than indicating a persistent difference between upwind and downwind concentrations. However, analysis of the top 5% of methane concentrations measured at the trailer does indicate that these disproportionately occurred when the wind is from the south-southwest (not shown here, but apparent in Figure 3.21 of the main report).

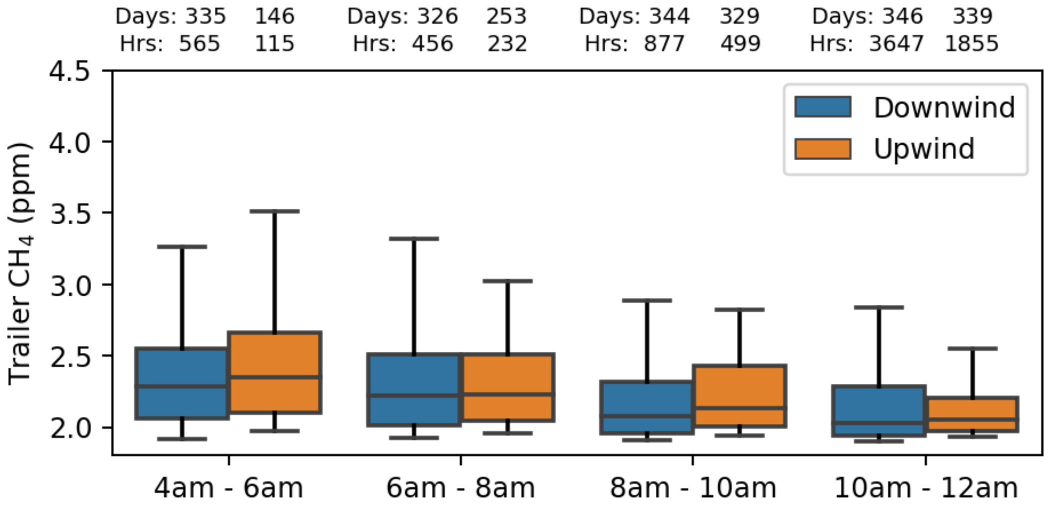

Figure E.5 All available trailer methane measurements grouped by whether the trailer was downwind or upwind of oil and gas-related operations, and for different times of day. Boxes show the 25th and 75th percentiles and whiskers indicate the 5th and 95th percentiles of the methane concentration. The horizontal lines within the boxes represent the median (50th percentile). The number of different days and the number of hours of data in each box plot are listed at the top of the figure.

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F. Methods for Health Guidance Value Identification, Evaluation, Selection, and Possible Adjustment

This Appendix presents the methods by which existing Health Guidance Values (HGVs) were identified, evaluated, selected, and possibly adjusted. HGVs other than an Office of Environmental Health Hazard Assessment (OEHHA) Reference Exposure Levels (REL) were designated as provisional HGVs (p-HGVs). The p-HGVs came from adoption or adjustment of existing values, application of OEHHA uncertainty factors (UFs) to the point of departure (POD) from an existing HGV, or use of an HGV for a structural analog of the target chemical.

a. Existing Health Guidance Values (HGVs)

This assessment considers health-based HGVs. Nuisance- or odor-based HGVs were not evaluated.

i. Noncancer HGVs

In general, noncancer HGVs are based on the most sensitive, relevant, adverse health effect reported in toxicological or epidemiological studies. These values are designed to protect the most sensitive individuals in the population by the inclusion of factors that account for uncertainties as well as individual differences in human susceptibility to chemical exposures. Noncancer HGVs commonly used in risk assessments, with a focus on values for the inhalation route of exposure and from US-based governmental bodies, are presented in Table F.1. The HGVs listed are from a variety of organizations tasked with protecting public health from chemical exposure, including OEHHA, the United States Environmental Protection Agency (US EPA), the Agency for Toxic Substances and Disease Registry (ATSDR), and the Texas Commission on Environmental Quality (TCEQ). The types of values vary by the intended exposure media (e.g., air, water), the targeted population (e.g., general population, children), and the considered critical effects (e.g., developmental/reproductive, all effects).

Table F.1 Examples of noncancer health guidance values (HGVs) with an emphasis on HGVs for the inhalation route of exposure from US-based governmental bodies.

Source	Value	Definition	Duration(s)	Route	Reference
OEHHA	Reference Exposure Level (REL)	An exposure at or below which adverse noncancer health effects are not expected to occur in a human population, including sensitive subgroups (e.g., infants and children), exposed for a specified duration.	Chronic, 8-hour, acute	Inhalation	OEHHA 2008
	Public Health Goal (PHG)	An estimate of a level of a contaminant in drinking water that is not anticipated to cause or contribute to adverse health effects, or that does not pose any significant risk to health including sensitive subgroups that comprise a meaningful portion of the general population (e.g., infants, children, pregnant women, elderly).	Chronic	Oral	California Safe Drinking Water Act 1996; OEHHA 2020a
	Child-Specific Reference Dose (chRD)	Numerical HGVs developed to address the specific sensitivity of children.	Chronic	All routes	OEHHA 2010
	Maximum Allowable	A level of exposure to a known reproductive toxicant (Proposition 65) that has no	Daily	All routes	California Code of

Source	Value	Definition	Duration(s)	Route	Reference
	Dose Level (MADL)	observable effect assuming exposure at one thousand times that level.			Regulations 1986
US EPA	Integrated Risk Information System (IRIS) Reference Concentration (RfC)	An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without appreciable risk of deleterious noncancer health effects during a lifetime.	Chronic	Inhalation	US EPA 1994
	Provisional Peer-Reviewed Toxicity Value (PPRTV) Provisional Reference Concentration (p-RfC)	An estimate (with uncertainty spanning perhaps an order of magnitude) of a continuous inhalation exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious health effects during chronic or subchronic exposure.	Chronic, subchronic	Inhalation	US EPA 2020b
	Health Effects Assessment Summary Tables	A provisional estimate (with uncertainty spanning perhaps an order of magnitude) of the daily exposure to the human population (including sensitive subgroups) that is likely to be without an appreciable risk of deleterious	Chronic, subchronic	Inhalation	US EPA 1997

Source	Value	Definition	Duration(s)	Route	Reference
	(HEAST) Reference Concentration (RfC)	effects during a lifetime (chronic) or portion of a lifetime (subchronic).			
ATSDR	Minimal Risk Level (MRL)	An estimate of the daily human exposure to a hazardous substance that is likely to be without appreciable risk of adverse noncancer health effects over a specified duration of exposure.	Chronic, intermediate, acute	Inhalation	ATSDR 2018a
TCEQ	Reference Values (ReV)	An estimate of an inhalation exposure concentration for a given duration to the human population (including susceptible subgroups) that is likely to be without an appreciable risk of adverse effects.	Chronic, acute	Inhalation	TCEQ 2015
American Conference of Governmental Industrial Hygienists (ACGIH)	Threshold Limit Value–Time-Weighted Average (TLV–TWA) 8-hr	The TWA concentration for a conventional 8-hr workday and a 40-hr workweek, to which it is believed that nearly all workers may be repeatedly exposed, day after day, for a working lifetime without adverse effect.	Chronic (occupational)	Inhalation	ACGIH 2015

Source	Value	Definition	Duration(s)	Route	Reference
	Threshold Limit Value–Short-Term Exposure Limit (TLV–STEL)	A 15-minute TWA exposure that should not be exceeded at any time during a workday, even if the 8-hr TWA is within the TLV–TWA. The TLV–STEL is the concentration to which it is believed that workers can be exposed continuously for a short period of time without suffering from: 1) irritation, 2) chronic or irreversible tissue damage, 3) dose-rate-dependent toxic effects, or 4) narcosis of sufficient degree to increase the likelihood of accidental injury, impaired self-rescue or materially reduced work efficiency. The TLV–STEL will not necessarily protect against these effects if the daily TLV–TWA is exceeded. The TLV-STEL usually supplements the TLV-TWA where there are recognized acute effects from a substance whose toxic effects are primarily of a chronic nature; however, the TLV-STEL may be a separate, independent exposure guideline.	Acute (occupational)	Inhalation	ACGIH 2015

ii. Cancer HGVs

Human health risk assessment is also used to assess lifetime cancer risk (i.e., the probability that an individual will develop cancer over a lifetime) resulting from exposure to a compound. When assessing the lifetime cancer risk by inhalation, it is typical to use cancer potency values, such as cancer potency factors (CPFs) (also known as slope factors [SFs]) or inhalation unit risks (IURs). Cancer potency values commonly used in risk assessment, with a focus on the inhalation route of exposure and US-based governmental bodies, are presented in Table F.2. The CPFs listed are from OEHHA and US EPA.

Table F.2 Examples of cancer potency values with a focus on values for the inhalation route of exposure and from US-based governmental bodies.

Source	Value	Definition	Route	Ref.
OEHHA	Cancer potency factor (CPF) and inhalation unit risk (IUR)	Characterize the relationship between an applied dose of a carcinogen and the risk of tumor appearance in a human. Usually expressed as a cancer slope factor [“potency” – in units of reciprocal dose – usually (mg/kg-body weight/day)$^{-1}$ or “unit risk” – reciprocal air concentration – usually (µg/m^3)$^{-1}$] for the lifetime tumor risk associated with lifetime continuous exposure to the carcinogen at low doses.	Inhalation / Oral	OEHHA 2009
US EPA IRIS	IUR	The upper-bound excess lifetime cancer risk estimated to result from continuous exposure to an agent at a concentration of 1 µg/m^3 in air. The interpretation of an inhalation unit risk would be as follows: if unit risk = 2×10^{-6} per µg/m^3, 2 excess cancer cases (upper bound estimate) are expected to develop per 1,000,000 people if exposed daily for a lifetime to 1 µg of the chemical per m^3 of air.	Inhalation	US EPA 2011
US EPA PPRTV	Provisional IUR (p-IUR)	An estimate of the increased cancer risk from inhalation exposure to a concentration of 1 µg/m^3 for a lifetime.	Inhalation	US EPA 2020b
US EPA HEAST	IUR	An estimate of the carcinogenic risk from inhalation exposure perconcentration unit in air (per µg/m^3).	Inhalation	US EPA 1997

b. Evaluation of Existing HGVs

i. HGV Evaluation Criteria

In human health risk assessment, it is typical to use one HGV for each compound-exposure duration combination to assess the potential health impacts from a specific compound exposure. When several HGVs are available for a specific compound, a hierarchy can be used to select HGVs that are of the highest quality or are the most relevant to the risk assessment. To create a hierarchy, each HGV source and type can be ranked based on parameters such as the extent of the external review process or the level of documentation provided. In addition, more specific quality parameters can be used to assess the relevancy of values for a particular risk assessment, such as the route of exposure or the population that the value is intended to protect (e.g., general population, occupational population).

For purposes of this Study of Neighborhood Air near Petroleum Sources (SNAPS) assessment, HGVs were evaluated for their applicability to general population inhalation risk assessment by the following criteria:

- The source provides documentation of HGV derivation (this was true of all HGV types in Tables F.1 and F.2)
- The level of peer review employed in HGV development (e.g., OEHHA and US EPA IRIS values undergo an extensive internal and external peer review process).
- The program that produced the HGV is still active, permitting updates or *de novo* development of HGVs (e.g., US EPA's HEAST program is no longer active).
- The HGV is based on a study conducted by the inhalation route (e.g., PHGs based on inhalation studies receive greater consideration than PHGs based on studies by other routes).
- The HGV is intended to protect the general population, including sensitive subgroups (e.g., OEHHA MADL values are based solely on developmental and reproductive toxicity studies; occupational values are not intended to protect the general population).
- The HGV was developed following established guidance so that its derivation was based on a consistent, documented methodology that can be reviewed. In many instances, such guidance undergoes external peer review and public comment processes as part of its development.
- The HGV reflects the legislative mandates and science policy choices that guide risk determinations in California. Only OEHHA HGVs are derived to meet this criterion.

Table F.3 shows the results of this analysis for key noncancer HGVs with a focus on inhalation values from US-based governmental bodies.

Table F.3 Evaluation of noncancer health guidance values (HGVs) per various criteria. "✓" means the HGV satisfies the criterion, "✓/-" means it satisfies the criterion somewhat or in some cases, and "-" means the HGV does not satisfy the criterion.

Source	**Description**	**External review**	**Public comment**	**Source program active**	**Intended for inhal. and/or derived from inhal. study**	**Intended to protect gen. pop., incl. sensitive subgroups**	**Established guidelines for HGV development**	**Developed by OEHHA to meet California risk standards**	**References**
OEHHA	RELs - chronic, 8-hr, acute	✓	✓	✓	✓	✓	✓	✓	California Health and Safety Code Division 26 1987; OEHHA 2008, 2020b, c
OEHHA	PHGs (noncancer endpoint)	✓	✓	✓	✓/—	✓	—	✓	California Safe Drinking Water Act 1996; OEHHA 2020a
US EPA IRIS	RfC - chronic	✓	✓	✓	✓	✓	✓	—	US EPA 1994, 2011, 2020c, e
ATSDR	MRLs - chronic, intermediate, acute	✓	✓	✓	✓	✓	✓	—	ATSDR 2018b, 2021; Chou et al. 1998
US EPA PPRTV	p-RfCs - chronic and subchronic	✓	—	✓	✓	✓	✓	—	US EPA 1994, 2002, 2020b, d

Source	Description	External review	Public comment	Source program active	Intended for inhal. and/or derived from inhal. study	Intended to protect gen. pop., incl. sensitive subgroups	Established guidelines for HGV development	Developed by OEHHA to meet California risk standards	References
OEHHA	chRD	✓	✓	✓	✓/—	✓/—	—	✓	California Health and Safety Code §901 2000; California Health and Safety Code Division 37 1993; OEHHA 2010, 2020b
US EPA HEAST	RfC - chronic, subchronic	—	—	—	✓	✓	✓	—	ECOS-DoD Suitability Work Group 2007; US EPA 1990, 1997
OEHHA	MADL	✓	✓	✓	✓/—	✓/—	✓	✓	California Code of Regulations 1986; OEHHA 2001, 2020b, d
TCEQ	ReV - chronic, acute	✓/—	✓	✓	✓	✓	✓	—	TCEQ 2015, 2020
ACGIH	TLV - occupational	✓/—	✓	✓	✓	—	✓	—	ACGIH 2015, 2020, n.d.

Abbreviations: Gen. pop., general population; incl., including; inhal., inhalation

ii. Ranking HGVs to Form a Hierarchy

The HGVs listed in Tables F.1 and F.2 were ranked to form hierarchies that would aid in selection of HGVs suitable for a general population inhalation health risk assessment, with a rank of 1 indicating an HGV is most appropriate and therefore prioritized in the assessment. This ranking was based on the evaluation criteria identified in the previous section. In addition to these criteria, the ranking of noncancer HGVs considered the intended exposure duration of the HGV (e.g., chronic values were ranked higher than subchronic values in chronic HGV selection; HGVs based on acute or developmental studies, the latter of which may be several weeks in duration, were deemed appropriate for use as acute HGVs).

Departures from the hierarchies were based on professional judgement. Factors that affected a departure included selection of a lower-ranked HGV that is based on a study of more appropriate duration or derived more recently with a more recent and higher quality critical toxicity study.

c. Selection of Noncancer Inhalation HGVs

i. Overview

Figure F.1 gives an overview of the process to select, adjust, or develop a provisional HGV (p-HGV) for use in SNAPS risk assessment. The decision tree includes four main tracks: (1) selection of an OEHHA REL if available; (2) selection of an existing HGV (other than an OEHHA REL) with potential adjustment to serve as a p-HGV; (3) development of a p-HGV based on the point of departure (POD) used for an existing HGV; (4) selection of a surrogate HGV using structural analogs for use as a p-HGV. For this report, any value other than an OEHHA REL is considered provisional. The four tracks are described in more detail below.

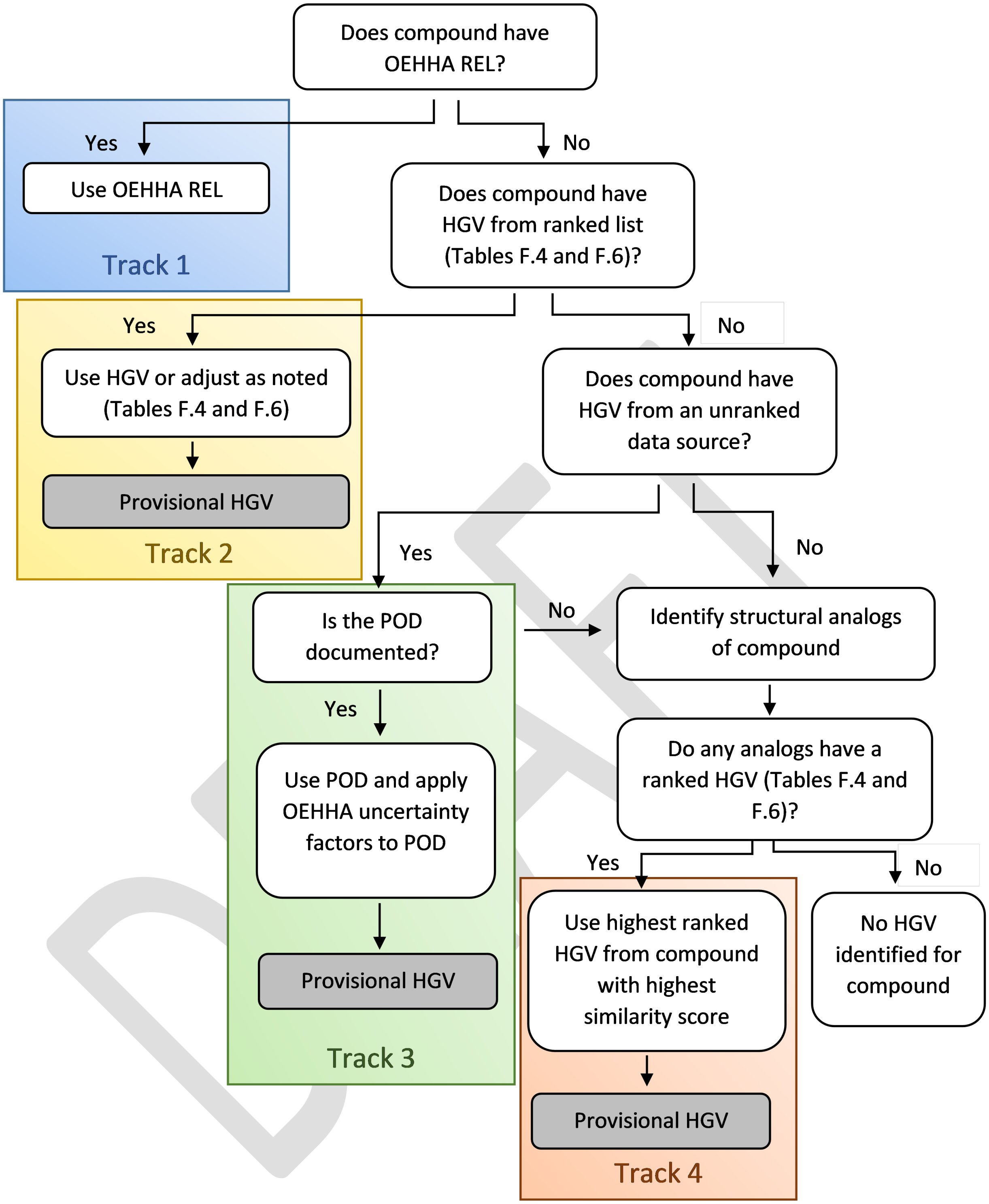

Figure F.1 Decision tree for noncancer health guidance value (HGV) selection, adjustment, and development. The decision tree follows four main tracks.

ii. Track 1: Use an OEHHA REL if available

If an OEHHA REL is available for a compound, that REL is used without adjustment.

iii. Track 2: In the absence of an OEHHA REL, adopt or adjust an existing HGV as a provisional HGV

Separate hierarchies of HGVs were developed for chronic (Table F.4) and acute (Table F.6) exposure durations based on a quality assessment of the sources and types of values (see Section F.b. Evaluation of Existing HGVs above).

1. Hierarchy of chronic noncancer inhalation HGVs

Based on the evaluation criteria in Table F.3, chronic noncancer HGVs were ranked for their applicability to a screening-level inhalation risk assessment for the general population (Table F.4). This hierarchy and professional judgement were used to identify the most appropriate HGV. Chronic or 8-hour RELs developed by OEHHA for inhalation exposures were ranked first as described in Track 1 (Figure F.1), followed by OEHHA PHGs based on a noncancer endpoint from an inhalation toxicity study. Subsequently ranked values are from OEHHA, US EPA, ATSDR, TCEQ, and ACGIH, which are ranked as presented in Table F.4. Table F.4 also indicates the general evaluation and adjustment approach that was applied to each HGV, where applicable, to derive a p-HGV for use in the risk assessment. These adjustments are described in more detail in Section F.c.iii.3 Adjustment of Existing HGVs .

If there were no available HGVs from Table F.4, then the sources listed in Table F.5 were consulted as a starting point for development of screening-level p-HGVs (see Section F.c.iv. Development of a Provisional HGV from the POD from an Existing HGV). In the event there was more than one data source available, professional judgement was used to select the most appropriate source.

Table F.4 Hierarchy for chronic noncancer inhalation health guidance value (HGV) selection.

Rank	Source	Description	Evaluation/adjustment	References
1	OEHHA	Chronic RELs/ 8-hr RELs	N/A	https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary
2	OEHHA	PHGs (noncancer endpoint derived from inhalation study)	Route-to-route extrapolation	https://oehha.ca.gov/water/public-health-goals-phgs
3	US EPA	IRIS RfC	N/A	https://iris.epa.gov/AtoZ/?list_type=alpha
4	ATSDR	Chronic inhalation MRLs	N/A	https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx
5	US EPA	Chronic PPRTV p-RfCs and screening level PPRTV p-RfCs	N/A	https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments
6	ATSDR	Intermediate inhalation MRLs	Subchronic to chronic extrapolation (where appropriate)	https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx
7	US EPA	Subchronic PPRTV p-RfCs and screening level PPRTV p-RfCs		https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments
8	OEHHA	chRD (based on inhalation study)	N/A	https://oehha.ca.gov/risk-assessment/chrd/table-all-chrds
9	US EPA	HEAST RfC Chronic	N/A	https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877

Rank	Source	Description	Evaluation/adjustment	References
10	US EPA	HEAST RfC subchronic	Subchronic to chronic extrapolation (where appropriate)	https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877
11	TCEQ	Chronic ReV	N/A	https://www.tceq.texas.gov/toxicology/esl/guidelines/about; https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=home.welcome
12	OEHHA	MADL (based on inhalation reproductive toxicity study)	N/A	https://oehha.ca.gov/proposition-65/proposition-65-list
13	ACGIH	TLV 8-hour TWA	Adjustment for daily 24 hr exposure; adjustment factor of 300 if based on human study, 3,000 if based on animal study	https://portal.acgih.org/s/store#/store/browse/cat/a0s4W00000g02f8QAA/tiles (not publicly available)
14	OEHHA	PHG (noncancer endpoint derived from non-inhalation study)	Route-to-route extrapolation	https://oehha.ca.gov/water/public-health-goals-phgs
15	OEHHA	chRD (based on oral study)	Route-to-route extrapolation	https://oehha.ca.gov/risk-assessment/chrd/table-all-chrds
16	US EPA	IRIS Reference Dose (RfD)	Route-to-route extrapolation	https://iris.epa.gov/AtoZ/?list_type=alpha
17	OEHHA	MADL (based on oral reproductive toxicity study)	Route-to-route extrapolation	https://oehha.ca.gov/proposition-65/proposition-65-list

Table F.5 Examples of possible data sources for chronic noncancer inhalation health guidance values (HGVs), or for relevant studies. Data sources are not ranked.

Value Type	Source	Description	References
State HGVs	TCEQ	Long-term Effects Screening Level (ESL) (health-based)	https://www.tceq.texas.gov/toxicology/esl/guidelines/about; https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=home.welcome
	Minnesota Dept. of Health	Chronic/ Subchronic air guidance values	https://www.health.state.mn.us/communities/environment/risk/guidance/air/table.html https://public.tableau.com/profile/mpca.data.services#!/vizhome/Airtoxicityvalues/Airtoxicityvalues
Occupational HGVs	California Division of Occupational Safety and Health (Cal/OSHA)	Permissible Exposure Levels (PELs)	https://www.dir.ca.gov/title8/5155table_ac1.html
	Occupational Safety and Health Administration (OSHA)	Permissible Exposure Levels (PELs)	https://www.osha.gov/dsg/annotated-pels/
	National Institute for Occupational Safety and Health (NIOSH)	Recommended Exposure Limits (RELs)	https://www.cdc.gov/niosh/npg/pgintrod.html
International HGVs	Health Canada	Indoor Air Reference Levels, Recommended	https://www.canada.ca/en/health-canada/services/publications/healthy-living/indoor-air-reference-levels.html

Value Type	Source	Description	References
		Exposure Limits (RELs)	https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html
Databases and primary sources	US EPA	CompTox Dashboard (includes compilation of governmental agency HGVs)	https://comptox.epa.gov/dashboard
	European Chemicals Agency (ECHA)	Registration dossiers	https://echa.europa.eu/information-on-chemicals/registered-substances
	Open literature	Toxicology and epidemiological/ occupational studies	Various: PubMed, ToxNet, ToxLine, etc.
Surrogate approach	-	Use inhalation HGV from Table F.4 for structurally similar chemical with molecular weight adjustment	-
Oral HGVs	ATSDR	Chronic Oral MRL	https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx

2. Hierarchy of acute noncancer inhalation HGVs

The evaluation criteria in Table F.3 were used to rank acute noncancer HGVs in a hierarchy for their applicability to a screening-level inhalation risk assessment for the general population (Table F.6). This hierarchy and professional judgement were used to identify the most appropriate HGV. Acute RELs developed by OEHHA for inhalation exposures took priority, as described in Track 1 (Figure F.1). ATSDR acute inhalation MRLs, TCEQ Acute ReVs, OEHHA MADLs that were based on developmental toxicity, and ACGIH TLV–STELs were ranked second, third, fourth, and fifth, respectively. Table F.6 also indicates the general evaluation and adjustment approach that was applied to each HGV, where applicable, to derive a p-HGV for use in the risk assessment (see Section F.c.iii.3 Adjustment of Existing HGVs below). If there were no available HGVs from Table F.6, then the sources listed in Table F.7 were used as a starting point for development of screening-level p-HGVs (see Section F.c.iv. Development of a Provisional HGV from the POD from an Existing HGV). In the event there was more than one data source available, professional judgement was used to select the most appropriate source.

Table F.6 Hierarchy for acute noncancer inhalation health guidance value (HGV) selection.

Rank	Source	Description	Evaluation/Adjustment	References
1	OEHHA	Acute RELs	N/A	https://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary
2	ATSDR	Acute inhalation MRLs	Time extrapolation to 1 hr (where appropriate)	https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx
3	TCEQ	Acute ReV	N/A	https://www.tceq.texas.gov/toxicology/esl/guidelines/about; https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=home.welcome
4	OEHHA	MADL (based on developmental toxicity)	Route-to-route extrapolation (where appropriate)	https://oehha.ca.gov/proposition-65/proposition-65-list
5	ACGIH	TLV-STEL	Adjustment for 1 hr exposure; adjustment factor of 300 if based on human study, 3,000 if based on animal study	https://portal.acgih.org/s/store#/store/browse/cat/a0s4W00000g02f8QAA/tiles (not publicly available)

Table F.7 Examples of possible data sources for acute noncancer inhalation health guidance values (HGVs) or for relevant studies. Data sources are not ranked.

Value Type	Source	Description	References
State HGVs	TCEQ	Short-term ESL (health-based)	https://www.tceq.texas.gov/toxicology/esl/guidelines/about; https://www17.tceq.texas.gov/tamis/index.cfm?fuseaction=home.welcome
	Minnesota Dept. of Health	Acute/Short-term air guidance values	https://www.health.state.mn.us/communities/environment/risk/guidance/air/table.html https://public.tableau.com/profile/mpca.data.services#!/vizhome/Airtoxicityvalues/Airtoxicityvalues
International	Health Canada	Short term exposure limits	https://www.canada.ca/en/health-canada/services/air-quality/residential-indoor-air-quality-guidelines.html
Occupational HGVs	Cal/OSHA	STELs, ceiling values	https://www.dir.ca.gov/title8/5155table_ac1.html
	OSHA	STELs, ceiling values	https://www.osha.gov/annotated-pels/table-z-1; https://www.osha.gov/annotated-pels/table-z-2
	NIOSH	STELs, ceiling values	https://www.cdc.gov/niosh/npg/pgintrod.html
	ACGIH	ceiling values	https://portal.acgih.org/s/store#/store/browse/cat/a0s4W00000g02f8QAA/tiles (not publicly available)
	US EPA	CompTox Dashboard (includes compilation	https://comptox.epa.gov/dashboard

Value Type	Source	Description	References
Databases and primary sources		of governmental agency HGVs)	
	ECHA	Registration dossiers	https://echa.europa.eu/information-on-chemicals/registered-substances
	Open literature	Toxicology and epidemiological/ occupational studies	Various: PubMed, ToxNet, ToxLine, etc.
Surrogate approach	-	Use inhalation HGV from Table F.6 for structurally similar chemical with molecular weight adjustment	-
Oral HGVs	ATSDR	Acute oral MRL	https://wwwn.cdc.gov/TSP/MRLS/mrlsListing.aspx

3. Adjustment of Existing HGVs

Tables F.4 and F.6 describe the adjustments for each HGV type appropriate for an inhalation risk assessment for the general population. HGVs were adjusted for the intended exposure duration (subchronic to chronic), route of exposure, and in the case of occupational values, to account for sensitive subgroups (e.g., children, elderly) or other uncertainties.

Adjustment for Subchronic to Chronic Exposure

HGVs that are intended for a subchronic exposure duration were adjusted by a subchronic UF (UF_S) to account for the potentially greater effects from a continuous lifetime exposure compared to a subchronic exposure. OEHHA guidelines recommend an adjustment based on the duration of the critical study ($UF_S = 1$ for study exposure durations >12% of estimated lifetime; $UF_S = \sqrt{10}$ for study exposure durations 8-12% of estimated lifetime; $UF_S = 10$ for study exposure durations <8% of estimated lifetime) (OEHHA 2008). However, for mice and rats, study exposure durations of 13 weeks or less are considered subchronic (OEHHA 2008).

Adjustment for Route-to-Route Extrapolation

When the highest ranked HGV was for a non-inhalation route, route-to-route extrapolation was performed. For example, if a chemical had a US EPA RfD for systemic effects (not portal of entry effects), route-to-route extrapolation was used to estimate an inhalation p-HGV.

To extrapolate oral exposures to inhalation exposures, toxicokinetic adjustments should be made to account for respiratory tract disposition, uptake, clearance, and metabolism. However, a thorough toxicokinetic analysis for each compound was beyond the scope of the assessment, and thus a screening level route-to-route adjustment was performed. Absorption by the oral and inhalation routes was gleaned from the literature when possible; otherwise, 100% absorption by both routes was assumed. In the most simple route-to-route extrapolation, the dose delivered to the target organ is assumed to be the same for oral and inhalation exposures. Using this assumption, a simple route-to-route extrapolation was performed by the equation below:

$$p\text{-}HGV_{Inhalation}\left(\frac{\mu g}{m^3}\right) = HGV_{Oral}\left(\frac{\mu g}{kg-day}\right) \times \left(\frac{Absorption_{Oral}(unitless)}{Absorption_{Inhalation}(unitless)}\right) \times \left(\frac{Body\ weight\ (kg)}{Air\ intake\ (\frac{m^3}{day})}\right)$$

Where:

Body weight = an adult body weight (70 kg)

Air intake = standard adult air intake (20 m^3/day) (OEHHA 2008)

Adjustment for Occupational Values

Adjustment for exposure duration: Chronic values

When the selected HGV was a long-term occupational exposure limit (OEL) such as an ACGIH TLV 8-hour TWA, an adjustment for exposure duration and UFs were applied to align with the risk assessment. Long-term OELs are intended to be protective during the workday rather than under continuous exposure conditions. Since chronic HGVs in the SNAPS assessment are meant to be protective during continuous daily exposure, the occupational HGV was therefore adjusted for exposure duration and breathing rates using the equation below. These adjustments assume an occupational air intake of 10 m^3/day, a general population air intake of 20 m^3/day, and a workweek of five days (OEHHA 2008):

$$p\text{-}HGV\left(\frac{\mu g}{m^3}\right) = \frac{Occupational\ value\ \left(\frac{\mu g}{m^3}\right) \times 10\ \frac{m^3}{day} \times 5\ \frac{days}{week}}{20\ \frac{m^3}{day} \times 7\ \frac{days}{week}}$$

An exception to this adjustment was ACGIH TLV 8-hour TWA values based on sensory or upper respiratory tract irritation; these values were not adjusted for continuous exposure because OEHHA considers trigeminally-mediated sensory irritation endpoints to be independent of exposure duration over the one-hour timescale, unless data indicate otherwise (OEHHA 2008). However, per OEHHA REL Guidance (OEHHA 2008), if there was lower respiratory tract involvement or tissue damage, the TLV *was* adjusted for continuous exposure.

Adjustment for exposure duration: Acute values

Most acute HGVs in the SNAPS assessment are meant to be protective during a 1-hour exposure. ACGIH STEL values intended for 15-minute exposures were adjusted for 1-hour exposure using Haber's Law as described in OEHHA guidance (OEHHA 2008). Haber's Law states that the product of the concentration (C) and time of exposure (T) required to produce a specific physiologic effect is equal to a constant level or severity of response (K), or C * T = K (Rinehart and Hatch 1964). When the duration of experimental exposure or the HGV duration differs from the desired exposure duration for which an acute exposure level is being calculated (in this case 1 hour), a modification of Haber's Law is used to adjust the experimental exposure duration to the desired duration of the acute exposure level:

$$C^n * T = K$$

where *n* is a chemical-specific parameter greater than zero (ten Berge et al. 1986). When available, the value of n was obtained from the literature. Otherwise, the default value of n = 1 for extrapolation from less than 1 hour to 1 hour was used.

Adjustment for susceptible populations: chronic and acute

Occupational HGVs are intended to protect the working population, which is considered a healthier population compared with the general population, and are derived using minimal (if any) UFs. Thus, in the event that an ACGIH TLV 8-hour TWA or ACGIH STEL was selected, it was adjusted by 300 if the underlying POD was based on a human study and 3,000 if based on an animal study. This factor is comprised of OEHHA's default intraspecies UF of 30 to protect sensitive populations (OEHHA 2008), an interspecies UF of 10 (if based on an animal study), and a remaining 10 to account for other potential uncertainties such as study duration, database deficiency, and the potential for additional susceptibility of children.

4. When an adjusted acute HGV is smaller than the chronic HGV

For the vast majority of compounds in the chemical universe, the acute HGV is expected to be higher than the chronic HGV, that is, the dose without effect is smaller with longer exposure duration. Thus, in the event that a provisional acute HGV derived through adjustment of an existing HGV was lower than the selected chronic HGV, the chronic HGV was used in place of this provisional acute HGV, the rationale being that such a provisional HGV carries greater uncertainty than a traditionally-derived chronic HGV.

iv. Track 3: Development of a provisional HGV based on the POD of an existing HGV

The HGVs for chronic and acute exposure durations were selected as described above per the relevant hierarchies and professional judgement (Tracks 1 and 2 of Figure F.1; Tables F.4 and F.6). If a ranked HGV from Tables F.4 or F.6 was not identified, the unranked data sources (Tables F.5 and F.7) were used as a starting point for development of a screening-level p-HGV. If there was more than one data source available, professional judgement was used to select the most appropriate source. HGVs for which a POD could be identified took priority.

The POD identified from a data source was used to derive a p-HGV for use in this risk assessment as described below. If the POD on which an HGV was based could not be identified (often due to lack of accessible documentation for the HGV), a p-HGV was established based on an inhalation HGV of a structural analog (see Section F.c.v. Track 4: Selection of a surrogate HGV using structural analogs below).

For each selected POD, the following were identified, when available, from the HGV documentation:

1) The critical study, including the species in which the critical study was conducted
2) The exposure concentrations, route, continuity, and duration in the critical study
3) The critical effect(s)
4) The POD for the effect(s), including its type (no-observed-adverse-effect-level [NOAEL], lowest-observed-adverse-effect-level [LOAEL], benchmark dose level, etc.)
5) Any continuity adjustments to the POD made by the source agency (e.g., to adjust for non-continuous exposure)
6) Any human equivalent concentration (HEC) adjustment to the POD (e.g., adjustment by the regional gas dose ratio)
7) Other adjustments to the POD, including UFs

The selection of the critical study, critical effect, and POD were not re-evaluated, nor were the adjustments to the POD for exposure duration or HEC determination. If no HEC adjustment was applied by the source agency to the POD, OEHHA did not make an HEC adjustment and instead applied OEHHA's default interspecies UF (UF_A) of 10 (OEHHA 2008).

The POD or POD_{HEC} was adjusted with UFs per OEHHA REL methodology (Table F.8) (OEHHA 2008) to derive a screening-level p-HGV. The types of UFs that may be used are as follows:

1) UF_L - LOAEL UF (adjusts for lack of a NOAEL in a study)
2) UF_S - subchronic UF (adjusts for exposure duration in derivation of a chronic REL; not applicable to acute RELs)
3) UF_{A-k} - toxicokinetic component of interspecies UF
4) UF_{A-d} - toxicodynamic component of interspecies UF
5) UF_{H-k} - toxicokinetic component of intraspecies UF
6) UF_{H-d} - toxicodynamic component of intraspecies UF
7) UF_D - database deficiency factor

Table F.8 Possible default uncertainty factors (UFs) used in deriving acute, 8-hour, and chronic Reference Exposure Levels (RELs) (from OEHHA 2008).

Method or Factor	*Values Used*	*REL Types*
	LOAEL uncertainty factor (UF_L)	
Values used:	1 NOAEL or benchmark used	A, 8, C
	6 LOAEL, mild effect	A
	10 LOAEL, severe effect	A
	10 LOAEL, any effect	8, C
	Interspecies uncertainty factor (UF_A)	
Values used for a combined interspecies UF (UF_A):	1 human observation	A, 8, C
	$\sqrt{10}$ animal observation in nonhuman primates	
	10 where no data are available on toxicokinetic or toxicodynamic differences between humans and a non-primate test species	
Values used for the toxicokinetic component (UF_{A-k}) of the interspecies UF:	1 where animal and human PBPK models are used to describe interspecies differences	A, 8, C
	2 for residual toxicokinetic differences in studies of non-primate species using the HEC approach or incomplete DAF model	
	$\sqrt{10}$ non-primate studies with no chemical- or species-specific kinetic data	

Method or Factor	*Values Used*	*REL Types*
Values used for the toxicodynamic component (UF_{A-d}) of the interspecies UF:	1 where animal and human mechanistic data fully describe interspecies differences. (*This is unlikely to be the case.)* 2 for residual susceptibility differences where there are some toxicodynamic data $\sqrt{10}$ non-primate studies with no data on toxicodynamic interspecies differences	A, 8, C
	Intraspecies uncertainty factor (UF_H)	
Values used for the toxicokinetic component of the intraspecies UF, (UF_{H-k}) for systemic toxicants:	1 human study including sensitive subpopulations (e.g., infants and children) 1 where a PBPK model including measured inter-individual variability is used $\sqrt{10}$ for residual susceptibility differences where there are some toxicokinetic data (e.g., PBPK models for adults only) 10 to allow for diversity, including infants and children, with no human kinetic data	A, 8, C
Values used for the toxicodynamic component of the intraspecies UF, (UF_{H-d}):	1 Human study including sensitive subpopulations (e.g., infants and children) $\sqrt{10}$ Studies including human studies with normal adult subjects only, but no reason to suspect additional susceptibility of children 10 Suspect additional susceptibility of children (e.g., exacerbation of asthma, neurotoxicity)	A, 8, C
	Subchronic uncertainty factor (UF_S)	
Values used:	1 Study duration >12% of estimated lifetime $\sqrt{10}$ Study duration 8-12% of estimated lifetime 10 Study duration <8% of estimated lifetime	C

Method or Factor	*Values Used*	*REL Types*
Database deficiency factor (UF_D)		
Values used:	1 No substantial data gaps $\sqrt{10}$ Substantial data gaps including, but not limited to, developmental toxicity	A, 8, C

*8, eight-hour REL; A, acute REL; C, chronic REL; DAF, dosimetric adjustment factor; HEC, human equivalent concentration; LOAEL, lowest observed adverse effect level; NOAEL, no observed adverse effect level; PBPK, physiologically-based pharmacokinetic modeling; REL, Reference Exposure Level; UF, uncertainty factor

**"Toxicodynamic" refers to the processes involved in the toxic action at the system, tissue or cellular level. "Toxicokinetic" refers to processes involved in deposition, absorption, distribution, metabolism and excretion of the compound.

***Individual UFs are rounded after multiplication, so two factors of $\sqrt{10}$ cumulate to 10, but one is rounded down to 3.

****The table presents suggested default values in particular situations; these may be modified in either direction by more specific data relating to the test and target populations considered.

A. Selection of the LOAEL uncertainty factor (UFL)

As presented in Table F.8, OEHHA's REL guidance (OEHHA 2008) provides the following default values for the LOAEL uncertainty factor (UF_L):

UF_L = 1 if NOAEL or benchmark is used (applies to acute, 8-hour, and chronic RELs)

UF_L = 6 if LOAEL for a mild effect is used (applies to acute RELs)

UF_L = 10 if LOAEL for a severe effect is used (applies to acute RELs)

UF_L = 10 if LOAEL is used for any effect (applies to 8-hour and chronic RELs)

For example, if the POD for an acute HGV is a LOAEL for eye irritation, an UF_L of 6 may be used if the irritation is mild and observed in a fraction of the subjects, whereas a UF_L of 10 may be used if the irritation is severe and/or irritation is observed in all subjects.

B. Selection of the toxicokinetic component of the intraspecies UF (UF_{H-k})

OEHHA applies an UF_{H-k} value of 10 as a default for gases acting systemically, and for particles that involve systemic exposure via dissolution and absorption in the lung or via the gastro-intestinal tract (OEHHA 2008). Gases that act solely at the portal of entry (i.e., lung or upper respiratory tract for inhaled toxicants) without involvement of metabolic activation or other complex kinetic processes use an UF_{H-k} of $\sqrt{10}$ (OEHHA 2008).

C. Selection of the toxicodynamic component of the intraspecies UF (UF_{H-d})

The UF_{H-d} is the toxicodynamic component of the intraspecies UF and is meant to account for human variability in the toxicodynamic action of a compound. Age is one factor that contributes to pharmacodynamic variability, which may be partly explained by changes in receptor levels (and functions) during the course of development (OEHHA 2008). OEHHA uses a default value of $\sqrt{10}$ for UF_{H-d}; however, for certain endpoints, there is evidence that the differences between infants or children and adults may be greater. These endpoints include neurotoxicity and causation or exacerbation of asthma. A value of 10 for UF_{H-d} was therefore used if one or more of the following conditions was met:

1) Neurotoxicity was the critical endpoint
2) Neurotoxicity and the critical endpoint occurred at similar exposure concentrations
3) The compound induces or exacerbates asthma
4) Effects observed around the POD (critical or non-critical endpoints) may be anticipated to affect children differentially (e.g., altered bone development)

D. Selection of the database uncertainty factor (UF_D)

A literature review of the toxicology database for each compound was beyond the scope of this assessment. Therefore, the selection of the value of UF_D was based on the following:

- Assessment of the database by other entities (e.g., US EPA's assessment of the database in IRIS documentation);
- Knowledge about the database gleaned from review of such documents as well as other assessments (e.g., Organisation for Economic Co-operation and Development Screening Information Dataset); and
- Professional judgment.

The types of studies that were commonly missing from a database and deemed a substantial data gap (thereby justifying a UF_D of $\sqrt{10}$) included adequate developmental toxicity studies (ideally in two species and by the inhalation route). However, information from oral developmental studies may be used to fill data gaps.

E. Assessment of the cumulative uncertainty factor ($UF_{cumulative}$)

In REL development, OEHHA typically limits cumulative UF values to no more than 3,000, as values >3,000 are generally taken to indicate that the source data are insufficient to support derivation of a REL (OEHHA 2008). However, for this screening-level health risk assessment, a maximum cumulative UF value of 10,000 was adopted. In the event that the cumulative UF was >10,000, a cumulative UF of 10,000 was applied to the POD to derive a provisional value.

F. When a developed provisional acute HGV is smaller than the chronic HGV

In the event that a provisional acute HGV developed by application of OEHHA UFs to a POD from an existing HGV was lower than the selected chronic HGV, the chronic HGV was used in place of this provisional acute HGV.

v. Track 4: Selection of a surrogate HGV using structural analogs

For some noncancer acute or chronic inhalation HGVs, documentation for an HGV was not available or was limited, precluding a complete understanding of the derivation of the HGV. Documentation was considered limited if it did not identify key risk assessment parameters (e.g., POD, critical study, critical endpoint, uncertainty factors) or provide underlying source information (e.g., OEL). If documentation was absent or limited, then a surrogate approach was used to determine a p-HGV. However, this approach was not applied to the metals (elemental compounds) since similar metals can vary significantly in toxicity, and even the same metal's toxicity can vary significantly depending on oxidation state (Egorova and Ananikov 2017).

The basic assumption when using structural surrogates is that a chemical's structure imparts properties that relate to the chemical's activity. Structure-activity relationships have long been used in risk assessment and are based on the observation that structurally similar chemicals frequently share structurally similar metabolites, act at the same target sites and through the same mode(s) of action, and thus exhibit similar toxicity. In this methodology, when no appropriate HGV is available through Tracks 1-3 (Figure F.1), a chemical's structural analogs can be identified and the corresponding HGVs considered.

Structural analogs of the target compound were identified using the US EPA CompTox Chemistry Dashboard, which identifies chemicals that match the target chemical with a Tanimoto similarity metric of >0.8 (calculated with Bingo Molecular Search Cartridge with associated Indigo fingerprints) (US EPA 2020a; Williams et al. 2017). The US EPA CompTox Chemistry Dashboard was searched for similar compounds with default settings.

Search results (in the form of Chemical Abstracts Service Registry Number [CAS RN]) were input into the Batch Search function of the US EPA Chemistry Dashboard. To identify ranked HGVs (Tables F.4 and F.6) for the analogs, Chemical Data was downloaded to Excel with presence in the following lists as the data fields to download:

- California Office of Environmental Health Hazard Assessment
- EPA: IRIS Chemicals
- EPA: PPRTV Chemical Report
- ATSDR: Minimal Risk Levels (MRLs) for Hazardous Substances

The list of CAS RN was also compared to the lists of CAS RN for which there are HEAST values, TCEQ ReV values (in the Texas Air Monitoring Information System [TAMIS] Web Interface), and ACGIH TLVs (ACGIH 2019; TCEQ 2020; US EPA 1997).

The analog with the highest similarity score and one or more HGVs from the ranked sources listed above was selected as the surrogate. The highest-ranked HGV (per the rankings in Tables F.4 and F.6) for this analog was selected and adjusted per the description in Tables F.4 and F.6. If a target chemical had two or more analogs with essentially identical similarity scores (e.g., 0.93-0.94) and ranked HGVs, the analog with the highest ranked value was selected as the surrogate chemical and its highest ranked HGV was selected and adjusted as described in Tables F.4 and F.6. If a target chemical had two or more analogs with identical similarity scores and *equivalently* ranked HGVs (e.g., two compounds with identical similarity scores both have OEHHA Acute RELs), then the geometric mean of these equivalently ranked HGVs was used.

d. Carcinogen Identification

A number of authoritative bodies evaluate compounds for the potential to cause cancer (carcinogenicity). These include OEHHA (via Proposition 65), the International Agency for Research on Cancer (IARC), the US EPA, and the US National Toxicology Program (NTP) of the US Department of Health and Human Services (IARC 2021; NTP 2016; OEHHA 2020d, n.d.; US EPA 2020c, 2021). One mechanism by which compounds are listed through Proposition 65 as known to the state to cause cancer is if one of the following designated authoritative bodies identifies the compound as a carcinogen: IARC, US EPA, NTP, the US Food and Drug Administration (US FDA), and NIOSH (OEHHA n.d.).

Many of these authoritative bodies classify the evaluated compounds based on the weight of evidence for carcinogenicity (e.g., possible, probable, known, etc.). For purposes of this SNAPS risk assessment, compounds were identified as carcinogens if they were classified by one or more authoritative bodies as follows:

- California's Proposition 65: listed as known to the state to cause cancer
- IARC: categorized as carcinogenic to humans (Group 1); probably carcinogenic to humans (Group 2A); or possibly carcinogenic to humans (Group 2B)
- US EPA IRIS: categorized by the inhalation route as carcinogenic to humans; likely to be carcinogenic to humans; suggestive evidence of carcinogenic potential (2005 guidelines); or Group A (Carcinogenic to Humans), Group B (Probably Carcinogenic to Humans), or Group C (Possibly Carcinogenic to Humans) (1986 guidelines) (US EPA 2021)
- NTP: categorized as known to be a human carcinogen, reasonably anticipated to be a human carcinogen

i. Selection of Cancer Inhalation HGVs

A ranking approach was used to identify the most appropriate cancer potency value for each carcinogen. As presented in Table F.9, IUR or CPFs developed by OEHHA generally took priority. In the absence of an OEHHA IUR or CPF, values from entities other than OEHHA were selected according to the hierarchy in Table F.9 and professional judgement. Evaluation and adjustment of non-OEHHA values was outside the scope of this assessment. If there were no available HGVs from Table F.9, then the sources listed in Table F.10 were used to identify other potential provisional HGVs.

Table F.9 Hierarchy for inhalation cancer potency values (CPFs).

Rank	Source	Description	References
1	OEHHA	IUR or CPF (from Hot Spots program, Proposition 65 No Significant Risk Level [NSRL], or cancer-based PHG based on inhalation study)	https://oehha.ca.gov/chemicals
2	US EPA	IRIS IUR	https://iris.epa.gov/AtoZ/?list_type=alpha
3	US EPA	PPRTV IUR	https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments
4	OEHHA	PHG (cancer endpoint derived from non-inhalation study)	https://oehha.ca.gov/water/public-health-goals-phgs
5	US EPA	HEAST IUR or Inhalation Slope Factor	https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877

Table F.10 Examples of possible data sources for inhalation cancer potency values (CPFs). Data sources are not ranked.

Value Type	Source	Description	References
State agencies	Minnesota Dept. of Health	Cancer air guidance value	https://www.health.state.mn.us/communities/environment/risk/guidance/air/table.html https://public.tableau.com/profile/mpca.data.services#!/vizhome/Airtoxicityvalues/Airtoxicityvalues
	TCEQ	IUR	https://www.tceq.texas.gov/toxicology/dsd/final; https://www17.tceq.texas.gov/tamis/index.cfm; published literature

Value Type	Source	Description	References
Surrogate approach	-	Per professional judgement, use inhalation HGV for structurally similar chemical with molecular weight adjustment	-
Oral Values	US EPA IRIS	IRIS oral slope factor, IRIS drinking water unit risk	https://iris.epa.gov/AtoZ/?list_type=alpha
	US EPA PPRTV	Oral slope factor	https://www.epa.gov/pprtv/provisional-peer-reviewed-toxicity-values-pprtvs-assessments
	US EPA HEAST	Oral slope factor	https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=2877

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SNAPS Lost Hills Draft Final Report Appendices

G. Risk Assessment Methods

This Appendix includes a brief introduction to health guidance values (HGVs), describes components of the exposure assessment (including exposure route, detection frequency [DF] requirements for inclusion of a compound in the analysis, assumptions about particle respirability and percent hexavalent chromium [CrVI] in total suspended particulate [TSP], exposure frequency, exposure duration, and breathing rates), risk estimation methods for cancer and noncancer risks, and a list of the risk assessments reviewed in preparation of this assessment.

a. Hazard Identification

i. Selection and Adjustment of Health Guidance Values (HGVs) for Detected Compounds

Human health risk assessment is used to characterize the potential for health effects after exposure to chemical contaminants. When assessing exposures, it is typical to use health guidance values (HGVs) for each compound, as appropriate, to assess the potential health impacts from a specific short- (acute) or long-term (chronic) exposure. An HGV is a chemical exposure level (e.g., a concentration in air or water), which is likely to pose little or no appreciable risk to human health. In general, HGVs are based on the most sensitive and relevant health effect reported in toxicological or epidemiological studies. An HGV is derived from a point of departure (POD), such as an exposure level in an animal experiment or an epidemiological study at which no effects (or at least minimal effects) are observed, or a benchmark dose (a statistical estimate of a dose with a low response rate). Extrapolation from this POD to an HGV for the target human population is generally performed by means of uncertainty factors (UFs). HGVs and estimates of exposure (which can come from air monitoring data) are used to express the health risk as a hazard quotient (HQ) for non-cancer effects or as a lifetime cancer risk (i.e., the probability that an individual will develop cancer over a lifetime) for each compound. HQs relating to the same target organ, endpoint, or mode of action can be summed to give a hazard index (HI) for non-cancer effects, and individual compound cancer risk values can be summed to give a cumulative lifetime cancer risk.

HGVs are a critical part of a risk assessment; however, derivation of an HGV per Office of Environmental Health Hazard Assessment (OEHHA) methodology is not possible for all compounds of concern due to lack of data and/or limited time and resources. Further, particularly for some compounds with potentially low toxicity (based on structure-activity relationship or other entities' HGVs) and/or limited exposure, the use of provisional HGVs (p-

HGVs) is a more efficient use of time and resources than more time-intensive derivations of traditional *de novo* HGVs, and may not alter the conclusions of the risk assessment.

OEHHA therefore developed methodology for selecting and adjusting existing HGVs beyond those adopted by the State for inhalation health risk assessment to establish p-HGVs and perform screening-level risk evaluations (see Appendix F for more detail).

b. Exposure Assessment

i. Exposure Route – Inhalation

The objective of this exposure assessment was to estimate the inhalation exposures of people in Lost Hills using the Study of Neighborhood Air near Petroleum Sources (SNAPS) air monitoring data. Although exposures from non-inhalation pathways (e.g., dermal absorption or ingestion of contaminated water, food, soil, or dust) could contribute to the cumulative hazard for some compounds (e.g., metals), evaluation of these was beyond the scope of this risk assessment. A recent health risk assessment for the area surrounding the Inglewood Oil Field in Los Angeles estimated that inhalation exposures were the Oil Field's greatest contributor to cancer risk in comparison to other modeled pathways (MRS 2020).

ii. Detection Frequency (DF) Requirements for Inclusion in Analysis

In this assessment, compounds were excluded from the cancer, acute noncancer, and chronic noncancer assessments if they were not detected. According to US EPA's Risk Assessment Guidance for Superfund, "[c]hemicals that are infrequently detected may be artifacts in the data due to sampling, analytical, or other problems" and recommends "[c]onsider[ing] the chemical as a candidate for elimination from the quantitative risk assessment if: (1) it is detected infrequently in one or perhaps two environmental media, (2) it is not detected in any other sampled media or at high concentrations, and (3) there is no reason to believe that the chemical may be present" (US EPA 1989). US EPA suggests a DF limit such as 5% as a way to perform this screen (US EPA 1989). For the cancer and chronic noncancer risk assessments, compounds were excluded if they were detected only once out of 20-50 samples (discrete samples), or had a DF less than 5% for those compounds measured hourly (real-time hydrocarbons). This DF requirement addresses not only the potential for artifacts in the data, but also the fact that infrequent detection does not support an assumption of chronic exposure. In contrast, all detected compounds were retained in the acute noncancer assessment regardless of DF as a health protective approach that assumes all detects are potentially valid.

iii. Assumptions

In order to estimate exposure, a number of health-protective assumptions were made with respect to human behavior and air concentrations. It was assumed that the outdoor air at the stationary monitoring site represented air concentrations experienced by people in Lost Hills. The reality is that air quality at the monitoring site is not necessarily the same as in other areas of Lost Hills, that people spend time inside vehicles and buildings and in their work environments, and that people may spend time outside of Lost Hills. Nevertheless, the health-protective assumptions made about the receptor's behavior and air concentrations are appropriate for a screening-level evaluation of health risk from ambient air.

1. Assumed 100% Respirability of Total Suspended Particulate

Total suspended particulate matter (TSP) was analyzed for metal content. TSP is comprised of particles of various diameters, a fraction of which may be considered respirable, that is, small enough to be inhaled and enter the respiratory tract. For purposes of this report, OEHHA defines the respirable fraction of TSP as particulate matter (PM) with a diameter less than 10 µm, also known as PM_{10}. Since PM_{10} was not measured in Lost Hills, the exact fraction of the collected TSP that is PM_{10} is unknown. However, OMNI and DRI (1989) determined particle size distributions in ambient air samples of different types collected in various parts of California (though most samples were collected in the San Joaquin Valley). These samples included diesel truck emissions, ski tour bus emissions (Mammoth Lakes), oil field crude oil combustion emissions, agricultural field burning emissions, dairy/feedlot emissions, and residential wood combustion emissions (the latter simulated in the laboratory). PM_{10} comprised an average of 84% of the TSP, with a geometric mean of 81%, and a median of 94%. Thus, it is reasonable and health-protective to assume that the entirety of the TSP in which the metals were measured was respirable (PM_{10}).

2. Assumed 1% of Total Chromium was Hexavalent Chromium (CrVI)

Chromium is present in the environment in multiple valence states that have widely different health effects. Total chromium within TSP samples was measured in this study. Human exposure to chromium occurs from both natural and anthropogenic sources (ATSDR 2012). Chromium is naturally present in the Earth's crust, so the main natural source of exposure is continental dust (ATSDR 2012). Anthropogenic releases account for 60-70% of total emissions of atmospheric chromium (ATSDR 2012). Chromium is present in the atmosphere primarily in particulate form (ATSDR 2012). Total chromium is comprised of chromium in various valence states, the major ones being trivalent chromium (CrIII) and hexavalent chromium (CrVI). In nature chromium occurs as CrIII, while CrVI rarely occurs naturally and is usually produced by anthropogenic sources (ATSDR 2012). About one-third of the atmospheric releases of chromium are believed to be CrVI (ATSDR 2012).

CrVI has greater toxicity than CrIII, and is listed by California's Proposition 65 as causing Cancer, Developmental Toxicity, Female Reproductive Toxicity, and Male Reproductive Toxicity (OEHHA n.d.). The relative amounts of CrIII versus CrVI are therefore important. Since the amount of CrIII versus CrVI was not determined in this study, the relative composition of the total chromium is unknown and must be estimated. OEHHA determined that an assumption of 1% CrVI and 99% CrIII was reasonable based on the following lines of evidence.

- There are no likely industrial sources of CrVI in the vicinity of Lost Hills.

  - Assembly bill (AB) 2588 requires facilities to report emissions of CrVI. In 2019 (2020 data not yet available), the only Kern County facility within 10 miles of Lost Hills with a non-zero reported emission was Liberty Composting Inc. on 12421 Holloway Road, with a reported emission of 0.0041 lb/year (CARB 2019). This facility is approximately 9 miles from the location of the stationary monitoring trailer. The distance and low emission rate make it unlikely that this facility substantially contributes to the CrVI levels in Lost Hills.
  - While chromium may be used in drilling muds, this is not a known source of atmospheric CrVI (ATSDR 2012). Chromium was not identified in the Lost Hills well stimulation disclosures for the period of monitoring (search done as of 10/14/20) (CalGEM 2021).
- The analyses of the metal concentrations by wind speed, correlation coefficients, and enrichment factors (Appendix J, Section c) suggest that chromium in the Lost Hills air samples is related to a crustal (soil/windblown dust) rather than an anthropogenic source. CrVI is rarely measured above the detection limit at the state network's closest air monitor (5558 California Ave, Bakersfield; CARB 2021). In the first three months of 2020 (most recent data in iADAM), CrVI was below the detection limit of 0.043 ng/m^3. In 2019, the 90th percentile concentration was below the detection limit (0.043 ng/m^3), meaning that CrVI was detected in no more than 10% of the samples that year. The maximum concentration measured in 2019 was 0.08 ng/m^3. In 2018, the 90th percentile was just above the detection limit of 0.02 ng/m^3 at 0.04 ng/m^3, with a maximum of 0.07 ng/m^3. In 2017, the 90th percentile was at the detection limit of 0.06 ng/m^3, meaning no more than 10% of samples were measured above the detection limit. The maximum value measured was 0.16 ng/m^3.
- The maximum value in 2019, along with the total chromium data from the Bakersfield monitor, can be used to estimate the highest theoretical CrVI concentration in Bakersfield in 2019 (maximum CrVI/minimum total chromium). The minimum total chromium level detected in 2019 was below the detection limit of 8.51 ng/m^3. To err on the side of overestimating the percent CrVI by minimizing the denominator, one can assume that total chromium was half the detection limit or 4.255 ng/m^3. The maximum CrVI value of 0.08 ng/m^3 detected in 2019 represents ~2% of this total chromium. The low end of the percent CrVI represented by the maximum CrVI level may be estimated by comparing the maximum CrVI value of 0.08 ng/m^3 to the maximum total chromium measured in 2019 (14 ng/m^3); CrVI represents ~0.6% of this total. Thus, CrVI was detected in no more than 10% of the samples in 2019, with a maximum percent CrVI of approximately 2%.
- Analysis of National Institute of Standards and Technology PM standard reference materials (SRMs) for urban PM (SRM 1648) and diesel PM (SRM 1650) by X-ray

absorption fine structure spectroscopy indicates the chromium in both SRMs is over 95% CrIII and could be 100%, and thus CrVI is less than 5% (Huggins et al. 2000).

Given this information, and the lack of known CrVI sources near Lost Hills, it is reasonable to assume that 1% of the total chromium measured in Lost Hills was CrVI.

iv. Exposure Frequency, Duration, and Breathing Rates

1. Cancer

Lifetime Exposure

OEHHA guidance states that a 70-year (lifetime) exposure duration is required to estimate population-wide risk and thus 70 years was used as the exposure duration in this assessment (OEHHA 2015). This is a health-protective assumption as it accounts for the possibility that some residents live their entire lives in Lost Hills.

Breathing Rates

Exposure through inhalation is a function of the breathing rate, the exposure frequency/duration, and the concentration of a substance in the air (OEHHA 2015). For residential exposure, the breathing rates are determined for specific age groups. In the cancer assessment, inhalation dose was calculated for each of the following age groups: 3rd trimester, 0<2 years, 2<16 years, and 16-70 years. These age-specific groupings are needed to properly use the age sensitivity factors (ASF) for cancer risk assessment. To be health-protective, OEHHA Guidance recommends that Tier 1 (screening-level) assessments, such as this SNAPS assessment, use the high-end point estimate (i.e., the 95th percentiles) breathing rates to avoid underestimating cancer risk to the public, including children. Thus, the 95th percentile breathing rates for the relevant age groups from Table 5.6 of OEHHA's Hot Spots Guidance (OEHHA 2015) were used.

2. Noncancer

Acute – Exposure of 1 Hour

Acute exposures were defined as when an individual breathes outdoor air continuously for 1-hr or 24-hrs while compound concentrations are at their highest measured concentration (maximum air concentration). In this assessment, maximum air concentrations are based on a 1-hr sample or 24-hr sample depending on the availability of the sampling data and the intended duration of the corresponding HGV (Appendix I, Table I.2). Further discussion on comparisons between 24-hr samples and HGVs intended for a 1-hr duration is presented in Appendix J, Section b. Benzene, toluene, and hydrogen sulfide were measured/detected by both real-time and discrete sampling; generally, real-time results were used in this analysis as they represent a maximum 1-hr average rather than maximum 24-hr average and there were a far greater number of samples.

Chronic – Exposure of 1 Year to a Lifetime

Chronic exposures were defined as when an individual breathes outdoor air continuously (24 hr/day, 365 day/year) for up to a lifetime (70 years) while the compound concentrations remain constant over the entire duration. The concentration used to represent chronic exposure was the average concentration for the monitoring period, using ½ the reporting limit for non-detects. Further discussion on the handling of non-detects is presented in Appendix G, Section c.ii.4.

Compounds that were detected in less than five percent of the real-time samples (trans-2-butene, cis-2-butene, trans-2-pentene, 1-pentene, cis-2-pentene, 1-hexene, n-undecane, n-dodecane) or only once in the discrete samples (acetonitrile, cis-1,3-dichloropropene, dimethyl disulfide, ethyl methyl sulfide, isobutyl mercaptan, trans-1,3-dichloropropene) were excluded from the chronic analysis as such a low DF is not indicative of chronic exposure.

c. Risk Estimation Methods

i. Cancer

1. Excess Cancer Risk

The excess cancer risk associated with breathing Lost Hills air for a lifetime (70 years) was estimated using standard methods. The term "excess" refers to the fact that without exposure to Lost Hills air, there is already a baseline risk of cancer due to other factors (age, genetics, other chemical exposures, diet, etc.). The excess cancer risk is the amount of risk that an exposure will *add* to the baseline cancer risk. The goal of this assessment was to determine the amount of risk that lifetime exposure to Lost Hills air adds to the baseline risk already present amongst the residents.

The first step in the cancer risk assessment was to determine the amount or dose of each compound that an individual breathing Lost Hills air would be exposed to. The dose is a function of the concentration in air, the breathing rate, and the exposure frequency. Since the breathing rate changes over the lifespan, doses were determined for each of the following age groups: 3rd trimester, 0<2 years, 2<16 years, and 16-70 years. Dose was estimated using the following equation (Equation 5.4.1.1 of OEHHA 2015):

$$DOSE_{air} = C_{air} \times \{BR/BW\} \times A \times EF \times 0.000001$$

Where:

$DOSE_{air}$ = Dose through inhalation (mg/kg-day)
C_{air} = Concentration in air (μg/m^3) [average concentration measured in Lost Hills]
{BR/BW} = Daily breathing rate normalized to body weight (L/kg-day) [95th percentile breathing rates found in Table 5.6 of OEHHA 2015]
A = Inhalation absorption factor (unitless) [assumed to be 1 (default)]
EF = Exposure frequency (unitless), days/365 days [to be health-protective, a value of 1 (exposure every day of the year) was assumed]

0.000001 = Micrograms to milligrams conversion, liters to cubic meters conversion

The doses determined for each age group were then used to estimate cancer risk for each age group. Cancer risk is calculated separately for specified age groups not only because of differences in breathing rates and thus doses, but also because of age differences in sensitivity to carcinogens. This age sensitivity is accounted for by using ASFs developed by OEHHA in the following equation (Equation 8.2.4 A, OEHHA 2015):

$$RISK_{inh\text{-}res} = DOSE_{air} \times CPF \times ASF \times ED/AT \times FAH$$

Where:

$RISK_{inh\text{-}res}$ = Residential inhalation cancer risk
$DOSE_{air}$ = Daily inhalation dose (mg/kg-day) [calculated above]
CPF = Inhalation cancer potency factor ($mg/kg\text{-}day^{-1}$) [from Appendix H, Table H.1]
ASF = Age sensitivity factor for a specified age group (unitless)
ED = Exposure duration (in years) for a specified age group
AT = Averaging time for lifetime cancer risk (years) [70 years (see text)]
FAH = Fraction of time spent at home (unitless) [to be health-protective, a value of 1 was used; this accounts for individuals that live, work, and attend daycare/school in Lost Hills over their lifetime]

The cancer risks calculated above for individual age groups are summed to estimate cancer risk for 70-year exposures with the following equation (equation from page 8-8, OEHHA 2015):

$$RISK_{inh\text{-}res} = (DOSE_{air}\text{ third trimester} \times CPF \times 10 \times 0.25/70\text{ years} \times FAH_{3rd\ tri\ <2}) + (DOSE_{air}\text{ age }0<2 \times CPF \times 10 \times 2/70 \times FAH_{3rd\ tri\ <2}) + (DOSE_{air}\text{ age }2<16 \times CPF \times 3 \times 14/70 \times FAH_{2<16}) + (DOSE_{air}\text{ age }16<70 \times CPF \times 1 \times 54/70\text{ years} \times FAH_{16\text{-}70})$$

Note that an inhalation unit risk (IUR), but not a CPF, was identified for isopropylbenzene. Cancer risk for isopropylbenzene was therefore estimated using the IUR:

$$RISK_{inh\text{-}res} = C_{air} \text{ x } IUR$$

Where:

$RISK_{inh\text{-}res}$ = Residential inhalation cancer risk
C_{air} = Concentration in air ($\mu g/m^3$) [average concentration measured in Lost Hills]
IUR = Inhalation Unit Risk ($(\mu g/m^3)^{-1}$) [from Table H.1 of Appendix H]

<u>Accounting for Early-life Susceptibility</u>

As described above, susceptibility to cancer due to early-life exposure to carcinogens was addressed through the use of age-specific breathing rates, which are highest for infants and children, as well as ASFs developed by OEHHA (2015).

2. Cumulative Cancer Risk

Cancer risks from different substances are generally treated as additive in risk assessment, in part because many carcinogens act through the common mechanism of DNA damage (OEHHA 2015). The additivity assumption is reasonable from a public health point of view. Other possible interactions of multiple carcinogens include synergism (effects are greater than additive) or antagonism (effects are less than additive). The type of interaction is both compound- and dose-dependent and in most cases data are not available to adequately characterize these interactions. Cumulative cancer risk was therefore estimated by summing the cancer risks for the individual compounds:

$$RISK_{Cumulative} = RISK_{Compound\ A} + RISK_{Compound\ B} + RISK_{Compound\ C} + RISK_{Compound\ D} + \ldots$$

Where:

$RISK_{Cumulative}$ = Cancer risk for all compounds from the inhalation pathway

$RISK_{Compound\ A,\ etc}$ = Cancer risk for each individual compound from the inhalation pathway

ii. Noncancer

1. Hazard Quotients

The potential for noncancer effects for each compound was expressed as a hazard quotient (HQ), which compares the estimated exposure to the HGV. An HQ that is less than or equal to one indicates that adverse health effects are not expected to result. As the HQ increases above one, the probability of human health effects increases by an undefined amount (OEHHA 2015). However, it should be noted that an HQ above one is not necessarily indicative of health impacts due to the application of uncertainty factors in deriving the HGVs.

An acute HQ is calculated to describe the risk of adverse health effects from short-term exposure to a compound (OEHHA 2015). A chronic HQ is calculated to describe the risk of adverse health effects from long-term exposure to a compound (OEHHA 2015).

$$Acute\ Hazard\ Quotient\ (unitless) = \frac{Maximum\ Air\ Concentration\ (\frac{\mu g}{m^3})}{Acute\ HGV\ (\frac{\mu g}{m^3})}$$

$$Chronic\ Hazard\ Quotient\ (unitless) = \frac{Annual\ Average\ Air\ Concentration\ (\frac{\mu g}{m^3})}{Chronic\ HGV\ (\frac{\mu g}{m^3})}$$

<u>Accounting for Sensitive Subpopulations</u>

With the exception of values developed for occupational settings, the HGVs selected were developed to be protective of sensitive subpopulations (e.g., pregnant women, children, and elderly) as stated in the definition of the HGVs or the policy of the source agencies (Appendix F). Protection of such sensitive groups is typically afforded by the use of uncertainty factors

(UFs) in development of HGVs. HGVs also are typically developed based on the species, sex, and life stage that is most sensitive to the compound. Since this assessment focuses on inhalation exposures, for which the respiratory system is often the target organ, asthmatics are commonly considered a sensitive subgroup (OEHHA 2008). The p-HGVs and OEHHA Reference Exposure Levels (RELs) are generally considered protective of this sensitive population, although a complete analysis of how asthmatics were considered in development of each HGV was not performed. Since occupational HGVs are developed for healthy working adults, an additional UF was applied to ensure the protection of sensitive subpopulations (Appendix F, Section c.iii.3 and Appendix H, Table H.2).

Overall, the HGVs used in this assessment are expected to be protective of the general population, including sensitive subgroups. However, since the true range of human variability in response to a particular compound is unknown, there could be a subset of the population that reacts to air concentrations below the HGVs (OEHHA 2008). Further, individuals who are hypersensitive or have a rare response that could not be predicted from human or animal studies may also react at lower air concentrations (OEHHA 2008).

2. Hazard Indices

Cumulative noncancer health risk from the multiple chemicals that may be simultaneously present in air was assessed by hazard indices (HIs). The hazard index (HI) is the sum of all HQs for compounds impacting the same target organ (OEHHA 2015). The target organ(s) for each compound was determined based on the critical effects used to establish the HGV for that compound (Appendix H, Table H.2, OEHHA 2008, 2019, 2020). The target organs are considered general categories that may include a variety of effects that occur at multiple locations in the organ (OEHHA 2008). HQs that affect different target organs were not summed because the relationship between toxicity to different organs is complex and often unknown (OEHHA 2008).

3. Comparison to Ambient Air Quality Standards

The criteria air pollutants measured in Lost Hills (particulate matter with a diameter less than 2.5 µm [$PM_{2.5}$], ozone, carbon monoxide, and lead) have health-based ambient air quality standards (AAQS). Hydrogen sulfide also has a standard, although it is not considered a criteria air pollutant. The measured concentrations of these compounds were compared to California Ambient Air Quality Standards (CAAQS) when available; otherwise, Primary (health-based) National Ambient Air Quality Standards (NAAQS) were used (CARB 2016). The standards selected for comparison are summarized in Appendix H, Table H.4. Each AAQS prescribes a specific sample duration or averaging time (e.g., 24 hours), as well as the treatment of these sample values (e.g., monthly average) (Appendix H, Table H.4). These requirements were followed as closely as possible in analysis of the Lost Hills data. However, some averaging times and treatments differ slightly due to the overall duration of the monitoring campaign and the frequency of sample collection. For example, data for comparison to the 24-hr $PM_{2.5}$ NAAQS are to be averaged over three years, but the Lost Hills monitoring campaign was only 11 months. These differences are detailed in Table 4.1 of the main report.

4. Handling of Non-detects to Calculate Means for Chronic Analyses

The air concentration used to represent chronic exposures was the mean over the monitoring period. In this assessment, the mean was calculated using ½ reporting limit (RL) for non-detects (samples detected at less than the RL). The simple substitution method of using ½ RL (or ½ detection limit) as a surrogate for values below the RL is a common method frequently used in risk assessment (US EPA 1991, 1992). However, this approach assumes that all values between zero and the RL could be present and that the average of those values can reasonably approximated by ½ RL, which is not always the case in environmental samples.

To determine if using ½ RL for non-detects was appropriate, means were calculated using the upper or lower bound and compared [analysis not shown]. The upper bound mean was calculated using the RL for non-detects as this is the highest air concentration possible for non-detects. The lower bound mean was calculated using zero for non-detects as this is the lowest possible air concentration. The HQ/HI results were similar when calculated with means using ½ RL, RL, or zero for non-detects. Although numerical values changed, the HQs and HIs that exceeded one remained the same.

The means using ½ RL, RL, or zero for non-detects were also used to calculate cancer risk. As expected, the cancer risk values were slightly altered and one compound exceeded the risk threshold in the upper bound analysis but not in the ½ RL or lower bound analyses. Specifically, perchloroethylene exceeded the one in a million risk threshold when using RL for non-detects, but was only ~2 per million. Although the numerical risk values changed slightly, the overall conclusions from the cancer analysis remained the same.

In conclusion, more sophisticated methods using statistical estimates for the values below the RL may be valuable but were deemed unnecessary in this assessment as the upper and lower bound resulted in the same overall health conclusions.

d. Risk Assessments Reviewed

The following risk assessments of communities near oil and gas production were reviewed to better understand methodological best practices, key metrics, and community risk outcomes:

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SNAPS Lost Hills Draft Final Report Appendices

H. Selected Health Guidance Values and Ambient Air Quality Standards

This Appendix presents the health guidance values (HGVs) selected for use in this assessment to evaluate cancer risks, acute noncancer risks, and chronic noncancer risks. One hundred and ten unique compounds were detected above the reporting limit (RL). Black carbon (BC) was measured as a surrogate for diesel particulate matter (diesel PM). Three compounds (particulate matter of diameter less than 2.5 µm [$PM_{2.5}$], ozone [O3], and carbon monoxide [CO]) were compared to ambient air quality standards (AAQSs) and were not assessed in the cancer or noncancer assessments. Chromium (Cr) was among the remaining 107 compounds considered, and was assumed to be 99% trivalent (CrIII) and 1% hexavalent (CrVI), making 108 total compounds. Of these, 20 were identified as carcinogens. After exclusion due to infrequent detection or lack of a cancer HGV, 17 carcinogens were evaluated in the cancer risk assessment. For the noncancer analysis, lead was excluded from the 108 because it was compared to AAQSs, leaving 107 compounds. Four were simple asphyxiants and excluded from the analysis, resulting in a total of 103 non-asphyxiant compounds. For these 103 compounds, 78 acute HGVs were identified. Eighty nine of the 103 met the minimum detection frequency (DF) requirements for the chronic analysis. Of these 89, 80 chronic HGVs were identified.

a. Selected Cancer Potency Values

Twenty carcinogens were identified among the chemicals detected in the air monitoring. Of these, cis-1,3-dichloropropene and trans-1,3-dichloropropene were excluded from consideration in the cancer risk assessment because they were detected in only one of 46 samples, so long-term exposure was considered unlikely (see Appendix G, Section b.ii). Of the 18 detected carcinogens that met the minimum DF requirement of 5% (hourly samples) or more than one detection (discrete samples), 17 had an HGV: acetaldehyde, arsenic, benzene, bis(2-ethylhexyl)phthalate, carbon tetrachloride, CrVI, diesel PM, ethylbenzene, formaldehyde, hexachloroethane, isoprene, isopropylbenzene, lead, naphthalene, nickel, perchloroethylene, and styrene (Table H.1). Sixteen of these seventeen carcinogens had an Office of Environmental Health Hazard Assessment (OEHHA) cancer potency HGV, though the OEHHA potency for isoprene is a draft value and is undergoing the formal process for adoption, including review by Scientific Review Panel on Toxic Air Contaminants. For isopropylbenzene, an inhalation unit risk developed by the Michigan Department of Environment, Great Lakes, and Energy (Michigan EGLE) was used (MDNRE 2010; Michigan EGLE 2015). Acrolein was recently classified by the International Agency for Research on Cancer (IARC) as probably carcinogenic to humans based on “sufficient” evidence of carcinogenicity in experimental animals (malignant lymphoma in mice and nasal cavity rhabdomyoma and squamous cell carcinoma combined in rat) and "strong" mechanistic evidence (IARC 2021a). However, a cancer HGV for acrolein was not identified from any ranked source or data source so its contribution to cancer risk could not be quantitatively evaluated.

Table H.1 Identification of carcinogens detected in Lost Hills and cancer health guidance values used in the cancer risk assessment, including inhalation cancer potency factors (CPFs) and inhalation unit risks (IURs). Carcinogens were identified based on classifications by the California Environmental Protection Agency's (CalEPA's) Proposition 65 program ("Listed" means compound is listed by the State as known to cause cancer; OEHHA 2020), the International Agency for Research on Cancer (IARC) (2021b), the US Environmental Protection Agency (US EPA) (IRIS; US EPA 2023a), and the US National Institutes of Health National Toxicology Program (NTP) (NTP 2016). OEHHA CPFs and IURs are from OEHHA (2009). Text in italics indicates that the classification is not indicative of carcinogenicity. cis-1,3-Dichloropropene and trans-1,3-dichloropropene were detected and are carcinogens but were excluded from the cancer risk assessment because they were detected in only one of 46 samples (see Appendix G). Black carbon (BC) was measured as a surrogate for diesel PM. Acrolein was recently classified by IARC as a Group 2A (Probable) carcinogen (IARC 2021a) but a cancer HGV was not identified for acrolein so its contribution to cancer risk could not be quantitatively evaluated.

Compound	CAS RN	CalEPA Prop. 65	IARC	US EPA	NTP	CPF (mg/kg-day)$^{-1}$	IUR (µg/m^3)$^{-1}$	Source	Basis (species, tumor type)
Acetaldehyde	75-07-0	Listed	Possible (Group 2B)	Probable (Group B2)[a]	Reasonably anticipated	0.010	0.0000027	OEHHA	Rat, nasal tumors
Arsenic (As)	7440-38-2	Listed	Known (Group 1)	Carcinogenic (Group A; Inorganic As)[a]	Known (As/ Inorganic As Compounds)	12	0.0033	OEHHA (values are for Inorganic As)	Human occupational exposure, lung tumors
Benzene	71-43-2	Listed	Known (Group 1)	Known/likely [b]/ Carcinogenic (Group A)[a]	Known	0.10	0.000029	OEHHA	Human occupational exposure, leukemia

Compound	CAS RN	CalEPA Prop. 65	IARC	US EPA	NTP	CPF (mg/kg-day)$^{-1}$	IUR (µg/m^3)$^{-1}$	Source	Basis (species, tumor type)
Bis(2-ethylhexyl) phthalate	117-81-7	Listed	Possible (Group 2B)	Probable (Group B2)[a]	Reasonably anticipated	0.0084	0.0000024	OEHHA	Mouse, liver carcinomas
Carbon tetrachloride	56-23-5	Listed	Possible (Group 2B)	Likely[c]	Reasonably anticipated	0.15	0.000042	OEHHA	Mouse, liver tumors
Chromium (Cr) VI	7440-47-3 (Cr); 18540-29-9 (CrVI)	Listed	Known (Group 1)	Known/likely (by inhalation)[b]/ Carcinogenic (Group A; by inhalation)[a]	Known (CrVI)	510	0.15	OEHHA	Human, lung cancer mortality
Diesel PM	N/A	Listed	Known (Group 1)	Likely[d]	Reasonably anticipated	1.1	0.00030	OEHHA	Human occupational exposure, lung tumors
Ethylbenzene	100-41-4	Listed	Possible (Group 2B)	*Not Classifiable (Group D)*[a]	N/A	0.0087	0.0000025	OEHHA	Rat, kidney tumors
Formaldehyde	50-00-0	Listed	Known (Group 1)	Probable (Group B1)[a]	Known	0.021	0.0000060	OEHHA	Rat, nasal squamous carcinoma

Compound	CAS RN	CalEPA Prop. 65	IARC	US EPA	NTP	CPF (mg/kg-day)$^{-1}$	IUR (µg/m^3)$^{-1}$	Source	Basis (species, tumor type)
Hexachloroethane	67-72-1	Listed	Possible (Group 2B)	Likely[c]	Reasonably anticipated	0.039	0.000011	OEHHA	Mouse, liver carcinoma
Isoprene	78-79-5	Listed	Possible (Group 2B)	N/A	Reasonably anticipated	0.019	0.0000054	OEHHA[e]	Rat, kidney, mammary gland, and testicular tumors
Isopropylbenzene	98-82-8	Listed	Possible (Group 2B)	*Cannot be determined*[b]*/ Not classifiable (Group D)*[a]	Reasonably anticipated	NR	0.0000105	Michigan EGLE[f]	Mouse, lung alveolar/ bronchiolar adenoma and carcinoma
Lead (Pb)	7439-92-1	Listed	Possible (Group 2B)	Probable (Group B2; lead and compounds [inorganic])[a]	Reasonably anticipated (Pb/Pb Compounds)	0.042	0.000012	OEHHA (values are for Pb and Pb compounds [inorganic])	Rat, kidney
Naphthalene	91-20-3	Listed	Possible (Group 2B)	*Cannot be determined*[b] /Possible (Group C)[a]	Reasonably anticipated	0.12	0.000034	OEHHA	Rat, nasal respiratory epithelial adenoma and nasal olfactory epithelial neuroblastoma

Compound	CAS RN	CalEPA Prop. 65	IARC	US EPA	NTP	CPF (mg/kg-day)$^{-1}$	IUR (µg/m^3)$^{-1}$	Source	Basis (species, tumor type)
Nickel (Ni)	7440-02-0	Listed	Known (Group 1) (Ni compounds)/Possible (Group 2B) (metallic Ni)	N/A	Known (Ni compounds); Reasonably anticipated (metallic Ni)	0.91	0.00026	OEHHA (values are for Ni and Ni compounds)	Human nickel refinery sinter plant workers, lung cancer mortality
Perchloroethylene	127-18-4	Listed	Probable (Group 2A)	Likely[c]	Reasonably anticipated	0.021	0.0000061	OEHHA	Mouse and rat, liver adenoma and carcinoma, Harderian gland tumors, hemangioma or hemangiosarcoma, mononuclear cell leukemia, testicular interstitial cell tumors, kidney tumors, brain glioma

Compound	CAS RN	CalEPA Prop. 65	IARC	US EPA	NTP	CPF (mg/kg-day)$^{-1}$	IUR (µg/m^3)$^{-1}$	Source	Basis (species, tumor type)
Styrene	100-42-5	Listed	Probable (Group 2A)	N/A	Reasonably anticipated	0.026	0.0000074	OEHHA[g]	Mouse, bronchioloalveolar adenomas and carcinomas

CAS RN, Chemical Abstracts Service Registry Number; N/A, not applicable; NR, not reported; Prop., Proposition

[a] 1986 Guidelines
[b] 1996 Proposed Guidelines
[c] 2005 Guidelines
[d] 1999 Revised Draft Guidelines
[e] Draft value undergoing the formal process for adoption, including review by Scientific Review Panel on Toxic Air Contaminants.
[f] Michigan Department of Environment, Great Lakes, and Energy (MDNRE 2010; Michigan EGLE 2015)
[g] CPF derived for Public Health Goal (OEHHA 2010); IUR calculated from CPF assuming 20 m^3/day ventilation and 70 kg body weight

b. Selected Noncancer HGVs

Noncancer HGVs represent the air concentration below which there is no appreciable risk of health effects when exposed to a compound for an acute (1-hr or 24-hr) or chronic (lifetime, 70 years) duration. The noncancer HGVs include OEHHA Reference Exposure Levels (RELs) and HGVs from other sources that have not been formally evaluated by OEHHA and are considered provisional HGVs (p-HGVs) in this analysis.

Acute and chronic noncancer HGVs were selected for each compound, when feasible, and some values were adjusted as described in Appendix F. Out of 107 compounds considered, 78 acute HGVs and 80 chronic HGVs were used in this analysis. The wide range in the HGVs reflects a wide range of toxicological potency among the compounds measured in Lost Hills. The selected HGVs and adjustments are described in Table H.2.

Compounds that were not detected above the RL during Study of Neighborhood Air near Petroleum Sources (SNAPS) monitoring were not included in the analysis. For several detected compounds, an acute or chronic HGV was not determined because no suitable existing HGV was identified (Table H.2). Acetylene, ethane, methane, and propane are simple asphyxiants (Cal/OSHA 2018). Simple asphyxiants act by limiting the availability of oxygen at high levels, rather than by direct toxicity. High concentrations are not expected to occur outdoors in a community setting, so these compounds were not evaluated in this assessment. Eleven compounds did not have suitable HGVs for both acute and chronic exposures and thus could not be evaluated quantitatively in the noncancer health assessment (bromine, calcium, chlorine, ethyl methyl sulfide [also low DF], iron, isobutyl mercaptan [also low DF], phosphorus, potassium, silicon, sulfur, and titanium). 1-hexene did not have an acute HGV and its low DF precluded inclusion in the chronic analysis. Hydrogen sulfide has a California Ambient Air Quality Standard (CAAQS) and is evaluated in the report Section 4.3.3; however, because there are acute and chronic RELs, it was included in the noncancer analysis as well. BC measurements are considered a surrogate for diesel PM exposure. Compounds with an oral HGV based on oral data were screened for the potential for respiratory sensitization using computer models and a review of the literature (Appendix J, Section a).

Table H.2 Selected acute and chronic noncancer health guidance values (HGVs). HGVs include OEHHA RELs and HGVs selected from other sources that are considered provisional HGVs (p-HGV) in this analysis. p-HGVs were used or adjusted and target organs recorded per the methodology described in Appendix F. No HGV indicates that a suitable p-HGV was not found/developed for this assessment. Low detection frequency (DF) indicates that the chemical's DF did not meet the inclusion criteria for the chronic analysis so a chronic HGV was not used (see Appendix G, Section b.ii for more details).

Compound	**CAS RN**	**Acute HGV Source (value $\mu g/m^3$)**	**Adjust-ments**	**Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)**	**Acute Target Organ(s)**	**Chronic HGV Source (value $\mu g/m^3$)**	**Adjust-ments**	**Chronic HGV ($\mu g/m^3$)**	**Chronic Target Organ(s)**
Acetaldehyde	75-07-0	OEHHA acute REL (470)	None	470	Eyes, Respiratory system	OEHHA chronic REL (140)	None	140	Respiratory system
Acetone	67-64-1	ATSDR acute inhalation MRL (20,000)	None	20,000 (24-hr)	Nervous system	TCEQ chronic ReV (16,000)	None	16,000	Nervous system
Acetonitrile	75-05-8	ACGH TLV-TWA (34,000)	POD[a]	590	Respiratory system	Low DF			
Acrolein	107-02-8	OEHHA acute REL (2.5)	None	2.5	Eyes, Respiratory system	OEHHA chronic REL (0.35)	None	0.35	Respiratory system
Aluminum	7429-90-5	No HGV				US EPA PPRTV chronic p-RfC (5)	None	5	Nervous system
Antimony	7440-36-0	ATSDR acute MRL (1)	None	1 (24-hr)	Respiratory system	ATSDR chronic MRL (0.3)	None	0.3	Respiratory - system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjustments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjustments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
Arsenic	7440-38-2	OEHHA acute REL (0.2)	None	0.2	Cardiovascular system, Developmental, Nervous system	OEHHA chronic REL (0.015)	None	0.015	Cardiovascular system, Developmental, Nervous system, Respiratory system, Skin
Barium	7440-39-3	No HGV				US EPA HEAST chronic RfC (0.5)	None	0.5	Developmental
Benzene	71-43-2	OEHHA acute REL (27)	None	27	Developmental, Hematologic system, Immune system	OEHHA chronic REL (3)	None	3	Developmental, Hematologic system, Nervous system
Benzoic acid	65-85-0	No HGV				US EPA PPRTV subchronic p-RfC (2)	UF_s[b]	0.7	Respiratory system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjust-ments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjust-ments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
Bis(2-ethylhexyl) phthalate	117-81-7	ATSDR acute oral MRL (0.003 mg/kg-day)	POD[a]	2	Endocrine system, Developmental	ATSDR intermediate inhalation MRL (3)	UF$_S$[b]	1	Developmental
n-Butane	106-97-8	TCEQ acute ReV (220,000)	None	220,000	General toxicity	TCEQ chronic ReV (24,000)	None	24,000	Nervous system
1-Butene	106-98-9	TCEQ acute ReV (62,000)	None	62,000	Nervous system	TCEQ chronic ReV (5,300)	None	5,300	General toxicity
cis-2-Butene	590-18-1	TCEQ acute ReV (34,000)	None	34,000	General toxicity	Low DF			
trans-2-Butene	624-64-6	TCEQ acute ReV (34,000)	None	34,000	General toxicity	Low DF			
Carbon tetrachloride	56-23-5	OEHHA acute REL (1,900)	None	1,900	Alimentary tract, Developmental, Nervous system	OEHHA chronic REL (40)	None	40	Alimentary tract, Developmental, Nervous system
Chromium III	16065-83-1	TCEQ acute ReV (12)	None	12	Respiratory system	ATSDR intermediate MRL (5 insoluble particles)	UF$_S$[b]	2	Immune system, Respiratory system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjust-ments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjust-ments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
Chromium VI	18540-29-9	TCEQ acute ReV (1.3)	None	1.3 (24-hr)	Respiratory system	OEHHA chronic REL (0.2)	None	0.2	Respiratory system
Copper	7440-50-8	OEHHA acute REL (100)	None	100	Respiratory system	ACGIH TLV-TWA (1,000 [dust])	Duration[c], General population UF[d]	1	Eyes, Respiratory system, Skin, Hematologic system
Cyclohexane	110-82-7	Used chronic HGV[e] (6,000)	None	6,000	Developmental	US EPA IRIS RfC (6,000)	None	6,000	Developmental
Cyclopentane	287-92-3	ACGIH TLV-TWA (1,720,000)	POD[a]	20,000	Eyes, Nervous system, Respiratory system, Skin	ACGIH TLV-TWA (1,720,000)	Duration[c], General population UF[d]	205	Eyes, Nervous system, Respiratory system, Skin
n-Decane	124-18-5	TCEQ acute ReV (5,800)	None	5,800	Eyes	TCEQ chronic ReV (1,100)	None	1,100	Hematological system, General toxicity

Compound	CAS RN	Acute HGV Source (value $\mu g/m^3$)	Adjust-ments	Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value $\mu g/m^3$)	Adjust-ments	Chronic HGV ($\mu g/m^3$)	Chronic Target Organ(s)
cis -1,3-Dichloropropene	10061-01-5 (542-75-6)	DPR Risk Assessment Acute	POD[a]	250 (24-hr)	General toxicity	Low DF			
trans -1,3-Dichloropropene	10061-02-6 (542-75-6)	DPR Risk Assessment Acute	POD[a]	250 (24-hr)	General toxicity	Low DF			
Diesel PM	N/A	No HGV				OEHHA chronic REL (5)	None	5	Respiratory system
m-Diethylbenzene	141-93-5	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	30,000 (24-hr)	Nervous system	DFG MAK (27,450)	POD[a]	34	Immune system

Compound	CAS RN	Acute HGV Source (value $\mu g/m^3$)	Adjust-ments	Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value $\mu g/m^3$)	Adjust-ments	Chronic HGV ($\mu g/m^3$)	Chronic Target Organ(s)
p-Diethylbenzene	105-05-5	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	30,000 (24-hr)	Nervous system	DFG MAK (27,450)	POD[a]	34	Immune system
2,2-Dimethylbutane	75-83-2	TCEQ acute ReV (19,000)	None	19,000	Endocrine system	TCEQ chronic ReV (670)	None	670	Nervous system
2,3-Dimethylbutane	79-29-8	TCEQ acute ReV (19,000)	None	19,000	Endocrine system	TCEQ chronic ReV (670)	None	670	Nervous system
Dimethyl disulfide	624-92-0	ECHA DNEL acute local general population (4,800)	POD[a]	19 (24-hr)	Respiratory system	Low DF			
2,3-Dimethylpentane	565-59-3	TCEQ acute ReV (34,000)	None	34,000	Nervous system	TCEQ chronic ReV (9,000)	None	9,000	General toxicity, Nervous system
2,4-Dimethylpentane	108-08-7	TCEQ acute ReV (34,000)	None	34,000	Nervous system	TCEQ chronic ReV (9,000)	None	9,000	General toxicity, Nervous system

Compound	CAS RN	Acute HGV Source (value µg/m³)	Adjust-ments	Acute HGV (µg/m³) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m³)	Adjust-ments	Chronic HGV (µg/m³)	Chronic Target Organ(s)
n-Dodecane	112-40-3	Structural surrogate to geomean of alkane analogs[h]	Molecular weight[g]	40,000	Nervous system, Endocrine system, Eyes	Low DF			
Ethanol	64-17-5	ACGIH TLV-STEL (1,880,000)	General population UF[cd]	6,270	Eyes, Respiratory System	ACGIH TLV-STEL (1,880,000)[e]	General population UF[cd]	6,270	Eyes, Respiratory System
Ethene	74-85-1	TCEQ acute ReV (570,000)	None	570,000	Alimentary tract	TCEQ chronic ReV (6,100)	None	6,100	Alimentary tract
Ethylbenzene	100-41-4	ATSDR acute MRL (20,000)	None	20,000 (24-hr)	Nervous system	OEHHA chronic REL (2,000)	None	2,000	Alimentary tract, Developmental, Endocrine system
m -Ethyltoluene	620-14-4	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	20,000 (24-hr)	Nervous system	Structural surrogate[f]: ethylbenzene OEHHA chronic REL (2,000)	Molecular weight[g]	2,000	Alimentary tract, Developmental, Endocrine system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjustments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjustments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
o -Ethyltoluene	611-14-3	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	20,000 (24-hr)	Nervous system	Structural surrogate[f]: ethylbenzene OEHHA chronic REL (2,000)	Molecular weight[g]	2,000	Alimentary tract, Developmental, Endocrine system
p-Ethyltoluene	622-96-8	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	20,000 (24-hr)	Nervous system	Structural surrogate[f]: ethylbenzene OEHHA chronic REL (2,000)	Molecular weight[g]	2,000	Alimentary tract, Developmental, Endocrine system
Fluorene	86-73-7	No HGV				US EPA IRIS RfD (0.04 mg/kg-day)	Route-to-route extrapolation[i]	100	Hematological system
Formaldehyde	50-00-0	OEHHA acute REL (55)	None	55	Eyes	OEHHA chronic REL (9)	None	9	Respiratory system
Freon 11	75-69-4	No HGV				US EPA PPRTV subchronic p-RfC (1,000)	UF$_S$[b]	100	Nervous system

Compound	CAS RN	Acute HGV Source (value μg/m^3)	Adjust-ments	Acute HGV (μg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value μg/m^3)	Adjust-ments	Chronic HGV (μg/m^3)	Chronic Target Organ(s)
Freon 113	76-13-1	ACGIH TLV-STEL (9,590,000)	Duration[j], General population UF[d]	7,990	Nervous system, Cardiovascular system	OEHHA PHG Update Memorandum (6.2 mg/L)	POD[a]	6,230	Alimentary tract
Freon 12	75-71-8	National Academy of Sciences EEGL (4,946,000)	POD[a]	20,000 (24-hr)	Cardiovascular system, Nervous system, Respiratory system	US EPA PPRTV chronic p-RfC (screening) (100)	None	100	General toxicity
n-Heptane	142-82-5	TCEQ acute ReV (34,000)	None	34,000	Nervous system	US EPA PPRTV chronic p-RfC (400)	None	400	Nervous system
Hexachloroethane	67-72-1	ATSDR acute MRL (60,000)	None	60,000 (24-hr)	Nervous system	US EPA IRIS RfC (30)	None	30	Nervous system
n-Hexane	110-54-3	TCEQ acute ReV (19,000)	None	19,000	Endocrine system	OEHHA chronic REL (7,000)	None	7,000	Nervous system
Hydrogen sulfide	7783-06-4	OEHHA acute REL (42)	None	42	Nervous system	OEHHA chronic REL (10)	None	10	Respiratory system

Compound	CAS RN	Acute HGV Source (value µg/m³)	Adjustments	Acute HGV (µg/m³) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m³)	Adjustments	Chronic HGV (µg/m³)	Chronic Target Organ(s)
Isobutane	75-28-5	TCEQ acute ReV (78,000)	None	78,000	Cardiovascular system, Nervous system, Respiratory system	TCEQ chronic ReV (24,000)	None	24,000	Nervous system
Isoprene	78-79-5	TCEQ acute ReV (3,900)	None	3,900	Developmental	TCEQ chronic ReV (390)	None	390	Nervous system
Isopropylbenzene	98-82-8	No HGV				US EPA IRIS RfC (400)	None	400	Alimentary tract, Endocrine system
Manganese	7439-96-5	TCEQ acute ReV (5)	None	5 (24-hr)	Respiratory System	OEHHA chronic REL (0.09)	None	0.09	Nervous system
2-Methylbutane	78-78-4	TCEQ acute ReV (200,000)	None	200,000	Nervous system	TCEQ chronic ReV (24,000)	None	24,000	Nervous system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjust-ments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjust-ments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
Methylcyclohexane	108-87-2	Structural surrogate[k] to geomean of C6-C10 alkane TCEQ acute ReVs (9,000)	Molecular weight[g]	9,000	Endocrine system, Nervous system, Eyes	HEAST chronic RfC (3,000)	None	3,000	Alimentary tract
Methylcyclopentane	96-37-7	Structural surrogate[f]: n-hexane TCEQ acute ReV (19,000)	Molecular weight[g]	19,000	Endocrine system	Structural surrogate[f]: n-hexane OEHHA chronic REL (7,000)	Molecular weight[g]	7,000	Nervous system
Methyl ethyl ketone	78-93-3	OEHHA acute REL (13,000)	None	13,000	Eyes, Respiratory system	US EPA IRIS RfC (5,000)	None	5,000	Developmental
2-Methylheptane	592-27-8	TCEQ acute ReV (19,000)	None	19,000	Nervous system	TCEQ chronic ReV (1,800)	None	1,800	General toxicity
3-Methylheptane	589-81-1	TCEQ acute ReV (19,000)	None	19,000	Nervous system	TCEQ chronic ReV (1,800)	None	1,800	General toxicity

Compound	CAS RN	Acute HGV Source (value $\mu g/m^3$)	Adjust-ments	Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value $\mu g/m^3$)	Adjust-ments	Chronic HGV ($\mu g/m^3$)	Chronic Target Organ(s)
2-Methylhexane	591-76-4	TCEQ acute ReV (34,000)	None	34,000	Nervous system	TCEQ chronic ReV (9,000)	None	9,000	General toxicity, Nervous system
3-Methylhexane	589-34-4	TCEQ acute ReV (34,000)	None	34,000	Nervous system	TCEQ chronic ReV (9,000)	None	9,000	General toxicity, Nervous system
2-Methylnaphthalene	91-57-6	Structural surrogate[f] to geomean of toluene (5,000) and m/p-xylene (22,000) OEHHA acute RELs	Molecular weight[g]	10,000	Eyes, Nervous system, Respiratory system	ACGIH TLV-TWA (3,000)	General population UF[cd]	1	Respiratory system
2-Methylpentane	107-83-5	TCEQ acute ReV (19,000)	None	19,000	Endocrine system	TCEQ chronic ReV (670)	None	670	Nervous system
3-Methylpentane	96-14-0	TCEQ acute ReV (19,000)	None	19,000	Endocrine system	TCEQ chronic ReV (670)	None	670	Nervous system

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjust-ments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjust-ments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
Naphthalene	91-20-3	MDH acute HBV (200)	POD[a]	204	Respiratory system	OEHHA chronic REL (9)	None	9	Hematological system, Respiratory system
Nickel	7440-02-0	OEHHA acute REL (0.2)	None	0.2	Immune system	OEHHA chronic REL (0.014)	None	0.014	Hematological system, Respiratory system
n-Nonane	111-84-2	TCEQ acute ReV (16,000)	None	16,000	Nervous system	US EPA PPRTV chronic p-RfC (20)	None	20	General toxicity, Nervous system
n-Octane	111-65-9	TCEQ acute ReV (19,000)	None	19,000	Nervous system	TCEQ chronic ReV (1,800)	None	1,800	General toxicity
n-Pentane	109-66-0	TCEQ acute ReV (200,000)	None	200,000	Nervous system	US EPA PPRTV chronic p-RfC (1,000)	None	1,000	General toxicity
1-Pentene	109-67-1	TCEQ acute ReV (34,000)	None	34,000	General toxicity	Low DF			
cis-2-Pentene	627-20-3	TCEQ acute ReV (34,000)	None	34,000	General toxicity	Low DF			

Compound	CAS RN	Acute HGV Source (value µg/m^3)	Adjust-ments	Acute HGV (µg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value µg/m^3)	Adjust-ments	Chronic HGV (µg/m^3)	Chronic Target Organ(s)
trans-2-Pentene	646-04-8	TCEQ acute ReV (34,000)	None	34,000	General toxicity	Low DF			
Perchloroethylene	127-18-4	OEHHA acute REL (20,000)	None	20,000	Eyes, Nervous system, Respiratory system	OEHHA chronic REL (35)	None	35	Alimentary tract
n-Propylbenzene	103-65-1	Structural surrogate[f]: ethylbenzene ATSDR acute MRL (20,000)	Molecular weight[g]	20,000 (24-hr)	Nervous system	US EPA PPRTV chronic p-RfC (screening) (1,000)	None	1,000	Developmental, Alimentary tract, Immune system
Propylene	115-07-1	No HGV				OEHHA chronic REL (3,000)	None	3,000	Respiratory system
Rubidium	7440-17-7	No HGV				US EPA PPRTV subchronic p-RfD (screening) (0.004 mg/kg-day)	Route-to-route extrapolation[i], UF_s[b]	1	Alimentary tract, General toxicity, Nervous system

Compound	CAS RN	Acute HGV Source (value $\mu g/m^3$)	Adjust-ments	Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value $\mu g/m^3$)	Adjust-ments	Chronic HGV ($\mu g/m^3$)	Chronic Target Organ(s)
Selenium	7782-49-2	No HGV				OEHHA chronic REL (20)	None	20	Alimentary tract, Cardiovascular system, Nervous system
Strontium	7440-24-6	No HGV				US EPA IRIS RfD (0.6 mg/kg-day)	Route-to-route extrapolation[i]	2000	Bone and teeth
Styrene	100-42-5	OEHHA acute REL (21,000)	None	21,000	Developmental, Eyes, Respiratory System	OEHHA chronic REL (900)	None	900	Nervous system
Tin	7440-31-5	No HGV				ACGIH TLV-TWA (2,000 inorganic)	Duration[c], General population UF[d]	2	Respiratory system
Toluene	108-88-3	OEHHA acute REL (5,000)	None	5,000	Eyes, Nervous system, Respiratory system	OEHHA chronic REL (420)	None	420	Eyes

Compound	CAS RN	Acute HGV Source (value μg/m^3)	Adjust-ments	Acute HGV (μg/m^3) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value μg/m^3)	Adjust-ments	Chronic HGV (μg/m^3)	Chronic Target Organ(s)
1,2,3-Trimethylbenzene	526-73-8	TCEQ acute ReV (15,000)	None	15,000	Nervous system	US EPA IRIS RfC (60)	None	60	Nervous system, Hematologic system
1,2,4-Trimethylbenzene	95-63-6	TCEQ acute ReV (15,000)	None	15,000	Nervous system	US EPA IRIS RfC (60)	None	60	Nervous system, Hematologic system
1,3,5-Trimethylbenzene	108-67-8	TCEQ acute ReV (15,000)	None	15,000	Nervous system	US EPA IRIS RfC (60)	None	60	Nervous system
2,2,4-Trimethylpentane	540-84-1	TCEQ acute ReV (19,000)	None	19,000	Nervous system	TCEQ chronic ReV (1,800)	None	1,800	General toxicity
2,3,4-Trimethylpentane	565-75-3	TCEQ acute ReV (19,000)	None	19,000	Nervous system	TCEQ chronic ReV (1,800)	None	1,800	General toxicity
n-Undecane	1120-21-4	Structural surrogate[h] to geomean of alkane analogs TCEQ acute ReVs	Molecular weight[g]	40,000	Nervous system, Endocrine system, Eyes	Low DF			

Compound	CAS RN	Acute HGV Source (value $\mu g/m^3$)	Adjust-ments	Acute HGV ($\mu g/m^3$) (noted if 24-hr duration)	Acute Target Organ(s)	Chronic HGV Source (value $\mu g/m^3$)	Adjust-ments	Chronic HGV ($\mu g/m^3$)	Chronic Target Organ(s)
Vanadium	7440-62-2	ATSDR acute MRL (0.8)	None	0.8 (24-hr)	Respiratory system	ATSDR chronic MRL (0.1)	None	0.1	Respiratory system
m/p-Xylene	108-38-3, 106-42-3	OEHHA acute REL (22,000)	None	22,000	Eyes, Nervous system, Respiratory system	OEHHA chronic REL (700)	None	700	Eyes, Nervous system, Respiratory system
o-Xylene	95-47-6	OEHHA acute REL (22,000)	None	22,000	Eyes, Nervous system, Respiratory system	OEHHA chronic REL (700)	None	700	Eyes, Nervous system, Respiratory system
Yttrium	7440-65-5	No HGV				ACGIH TLV-TWA (1,000)	Duration[c], General population UF[d]	0.1	Respiratory system
Zinc	7440-66-6	DFG MAK (100 [respirable])	POD[a]	20	Respiratory system, Immune system	DFG MAK (2000 [inhalable])	POD[a]	0.2	Respiratory system

ACGIH, American Conference of Governmental Industrial Hygienists; AEGL, Acute Exposure Guideline; ATSDR, Agency for Toxic Substances and Disease Registry; C6-C10, six to 10 carbon atoms in length; CAS RN, Chemical Abstracts Service Registry Number;

DF, detection frequency; DFG MAK, Deutsche Forschungsgemeinschaft maximum workplace concentration; DNEL, Derived No Effect Level; DPR, California Department of Pesticide Regulation; ECHA, European Chemicals Agency; EEGL, Emergency Exposure Guidance Level; geomean, geometric mean; HBV, Health-Based Value; HEAST, Health Effects Assessment Summary Tables; HGV, health guidance value; IRIS, Integrated Risk Information System; MADL, Maximum Allowable Dose Level; MDH, Minnesota Department of Health; MRL, Minimal Risk Level; NOAEL, No Observed Adverse Effect Level; OEHHA, Office of Environmental Health Hazard Assessment; PHG, Public Health Goal; POD, point of departure; PPRTV, Provisional Peer-Reviewed Toxicity Value; p-RfC, Provisional Reference Concentration; p-RfD, Provisional Reference Dose; REL, Reference Exposure Level; ReV, Reference Value; RfC, Reference Concentration; RfD, Reference Dose; TCEQ, Texas Commission on Environmental Quality; TLV-STEL, Threshold Limit Value–Short-Term Exposure Limit; TLV-TWA, Threshold Limit Value–Time-Weighted Average; UF, uncertainty factor; UF_S, subchronic uncertainty factor; US EPA, United States Environmental Protection Agency

Sources of HGVs in table: ACGIH 2020; ATSDR 2023; DFG 2023; DPR 2015; ECHA 2023; MDH 2004; NRC 2008; OEHHA 2011, 2023; TCEQ 2023; US EPA 1997, 2023a, b

[a] The POD from the selected provisional health guidance value (p-HGV) was adjusted per OEHHA (2008) and Appendix F. Detailed description of the adjustment are in Table H.3.
[b] The p-HGV was established for subchronic exposure durations and adjusted to chronic durations using an UF (UF_S). UF_s was applied per OEHHA (2008): benzoic acid (UF_s = 3), bis(2-ethylhexyl)phthalate (UF_S = 3), chromium III (UF_s = 3), freon 11 (UF_s = 10), rubidium (UF_s = 10)
[c] Duration adjustment for occupational values to continuous exposure using breathing rate and exposure time per Appendix F Section iii.3. 2-Methylnaphthalene and ethanol were not adjusted because their critical endpoints were irritation of upper respiratory tract and/or eyes as discussed in Appendix F, Section iii.3.
[d] General population UF to account for sensitive subgroups as discussed in Appendix F, Section iii.3. 2-methylnaphthalene (UF = 3,000), copper (UF = 300), cyclopentane (UF = 3,000 based on studies discussed in cyclopentane ACGIH TLV document that was established by analogy to pentane; ACGIH 2001), ethanol (UF = 300), freon 113 (UF = 300), tin (UF = 300), yttrium (UF = 3000)
[e] If the acute p-HGV was less than the chronic HGV, then the chronic value was used. In these cases, professional judgement determined that the chronic HGVs were more reliable and were considered protective of acute exposures (Appendix F, Section iii.4). For ethanol, an acute p-HGV was used for the chronic p-HGV as the ACGIH noted that the acute effects occur well below concentrations that have been shown to cause chronic effects (ACGIH 2009).

[f] Structural surrogate. Methodology for selecting structural surrogates and corresponding p-HGVs is described in Appendix F, Section v.

[g] Molecular weight. Structural surrogate HGVs in parts per million (ppm) are used for the target compound's p-HGV. The ppm of the target compound is converted to μg/m^3. Thus, the surrogate p-HGV will be equivalent in ppm but may not be equivalent in μg/m^3 due to differences in molecular weight.

[h] Structural surrogate to geometric mean of alkane analogs. Several alkanes had the same similarity score and p-HGV source (TCEQ acute ReV). Thus, a geometric mean (5,791 ppb) of the TCEQ acute ReVs was used: n-pentane (200,000 μg/m^3), nervous system; n-hexane (19,000 μg/m^3), nervous system; heptane (34,000 μg/m^3), nervous system; octane (19,000 μg/m^3), nervous system; nonane (16,000 μg/m^3), nervous system; decane (5,800 μg/m^3), eyes. The target organ of the compound was considered to be all of the target organs listed for the analogs.

[i] Route-to-route extrapolation was performed when the p-HGV was intended for a route of exposure other than inhalation per Appendix F, Section iii.3. Fluorene, rubidium: assumed 100% absorption by oral and inhalation routes; strontium: assumed 85% absorption by oral route and 100% by inhalation route (Forbes and Reina 1972 as cited by ATSDR 2004);.

[j] Duration adjustment using Haber's Law following OEHHA 2008.

[k] Structural surrogate to geometric mean of alkane analogs. Fifty-five alkanes had the same similarity score and p-HGV source (TCEQ acute ReV). Thus, a geometric mean (2247 ppb) of the TCEQ acute ReVs was used. The target organ of the compound was considered to be all of the target organs listed for the analogs.

Table H.3 Noncancer provisional health guidance values (p-HGVs) derived from the point of departure (POD) of an existing health guidance value (HGV). p-HGVs were derived by adjustment of PODs per OEHHA (2008) and Appendix F.

Compound	**HGV Type**	**POD (µg/m^3)**	**Spec-ies**	**Critical Effect(s)**	**Time extrapolation[a]; $POD_{Adjusted}$ (µg/m^3)**	**Route to Route Extrapolation; $POD_{Adjusted}$ (µg/m^3)**	**UF_L**	**UF_A**	**UF_H**	**UF_S**	**UF_D**	**Cumul-ative UF**	**p-HGV (µg/m^3)**
Acetonitrile	Acute	LOAEL = 67,000	H	Chest tightness and cooling sensation in lung	4 hrs to 1 hr, n = 3; 106,600	N/A	6	1	30	N/A	1	180	590
Bis(2-ethylhexyl) phthalate	Acute	LOAEL = 1 mg/kg-day	R	Altered glucose homeostasis in adult rat offspring following fetal exposure	N/A (oral study)	Oral/Inhalation absorption: 50%/ 100%;[b] 1,750	10	10	10	N/A	1	1000	2
Cyclohexane	Acute	NOAEL = 860,000	H	Neurobehavorial effects	4 hrs to 1 hr, n = 3; 1,400,000	N/A	1	1	100	N/A	1	100	14,000
Cyclopentane	Acute	ACGIH n-pentane NOAEL = 14,300,000 (for cyclopentane molecular weight)	H	Irritation	10 min to 1 hr, n = 1; 2,390,000	N/A	1	1	100	N/A	1	100	20,000

Compound	HGV Type	POD (µg/m³)	Spec-ies	Critical Effect(s)	Time extrapolation[a]; POD$_{Adjusted}$ (µg/m³)	Route to Route Extrapolation; POD$_{Adjusted}$ (µg/m³)	UF$_L$	UF$_A$	UF$_H$	UF$_S$	UF$_D$	Cumul-ative UF	p-HGV (µg/m³)
cis -1,3-Dichloropropene	Acute	BMCL HEC non-occupational = 50,000	R	Weight decrements	Completed in HEC for 24 hrs	N/A	1	6	30	N/A	1	200	250
trans -1,3-Dichloropropene	Acute	BMCL HEC non-occupational = 50,000	R	Weight decrements	Completed in HEC for 24 hrs	N/A	1	6	30	N/A	1	200	250
m-Diethylbenzene	Chronic	NOAEL = 190,000	R	Decreased leukocyte and lymphocyte counts	Adjust for continuous exposure; 34,000	N/A	1	10	30	3	1	1000	34
p-Diethylbenzene	Chronic	NOAEL = 190,000	R	Decreased leukocyte and lymphocyte counts	Adjust for continuous exposure; 34,000	N/A	1	10	30	3	1	1000	34

Compound	HGV Type	POD (µg/m^3)	Species	Critical Effect(s)	Time extrapolation^{a}; $POD_{Adjusted}$ (µg/m^3)	Route to Route Extrapolation; $POD_{Adjusted}$ (µg/m^3)	UF_L	UF_A	UF_H	UF_S	UF_D	Cumulative UF	p-HGV (µg/m^3)
Dimethyl disulfide	Acute	NOAEL = 19,000	R	Degeneration of nasal olfactory epithelium	24 hr exposure, no adjustment	N/A	1	10	100	N/A	1	1000	19
Freon 113	Chronic	LOAEL = 523,000	H	Hepatobiliary dysfunction	Occupational to continuous; 187,000	N/A	3	1	10	1	1	30^{c}	6,230
Freon 12	Acute	NOAEL = 4,945,603	H	Lack of effects on EKG, cognition, neurological function, pulmonary function, clinical chemistry	NOAEL applies to up to 8 hr acute exposure as well as repeated 8 hr daily exposures; no adjustment	N/A	1	1	100	N/A	3	300	20,000
Isopropylbenzene	Acute	LOAEL = 1,500,000	H	Eye and upper respiratory pain	Duration unknown, no adjustment	N/A	6	1	100	N/A	1	600	3,000
Naphthalene	Acute	NOAEL = 204,000	M	Swelling, sloughing of cells of larger airways	1 hr exposure, no adjustment	N/A	1	10	100	N/A	1	1000	204.3

Compound	HGV Type	POD ($\mu g/m^3$)	Species	Critical Effect(s)	Time extrapolation[a]; $POD_{Adjusted}$ ($\mu g/m^3$)	Route to Route Extrapolation; $POD_{Adjusted}$ ($\mu g/m^3$)	UF_L	UF_A	UF_H	UF_S	UF_D	Cumulative UF	p-HGV ($\mu g/m^3$)
Zinc	Acute	NOAEL = 400 zinc (as part of zinc oxide)	H	Lack of zinc fever or increase in inflammation markers	2 hr to 1 hr, n = 3; 500	N/A	1	1	30	N/A	1	30	20
Zinc	Chronic	LOAEL = 1,800	H	Greater chronic production of phlegm	Occupational to continuous; 600	N/A	10	1	30	10	1	3000	0.2

ACGIH, American Conference of Governmental Industrial Hygienists; BMCL, Benchmark Concentration Lower Bound; EKG, electrocardiogram; H, human; HEC, Human Equivalent Concentration; HGV, health guidance value; hr, hour; LOAEL, lowest observed adverse effect level; M, mouse; mg/kg-day, milligram per kilogram body weight per day; N/A, not applicable; NOAEL, no observed adverse effect level; p-HGV, provisional health guidance value; POD, point of departure; R, rat; UF, uncertainty factor; UF_A, interspecies uncertainty factor; UF_D, database deficiency uncertainty factor; UF_H, intraspecies uncertainty factor; UF_L, lowest observed adverse effect level uncertainty factor; UF_S, subchronic uncertainty factor

[a] Time extrapolation for acute values based on Haber's law ($C_1^n \times T_1 = C_2^n \times T_2$) as described in OEHHA (2008) and Appendix F, Section iii.3. Time extrapolation for chronic value based on occupational adjustment described in Appendix F, Section iii.3.
[b] Route to route extrapolation assumes oral/inhalation absorption of 50%/100% (ATSDR 2019; DFG 2016), body weight of 70 kg, and daily breathing rate of 20 m^3/day.
[c] UFs determined in the Public Health Goal memorandum were used (OEHHA 2011).

d. Ambient Air Quality Standards

*Table H.4 Ambient air quality standards used to evaluate the criteria pollutants and hydrogen sulfide (hydrogen sulfide is not a criteria pollutant but has a California standard). California Ambient Air Quality Standards (CAAQS) were used when available; otherwise, Primary National Ambient Air Quality Standards (NAAQS) were used. Primary NAAQS are the levels of air quality necessary, with an adequate margin of safety, to protect the public health. Adapted from CARB (2016a).**

Pollutant	Source of Standard	Averaging Time	Concentration[a]	Basis of Standard	Method
Fine particulate matter ($PM_{2.5}$)	National	24-hr	35 µg/m^3 [b]	• Mortality (including mortality from respiratory and cardiovascular conditions) • Cardiovascular effects (including ER visits and hospital admissions for ischemic heart disease and heart failure) • Respiratory effects (including ER visits and hospital admissions for COPD and respiratory infection among adults or people of all ages, and increased respiratory symptoms and decreased lung function in children with asthma) (US EPA 2020)	Inertial Separation and Gravimetric Analysis
	California	24-hr samples, Annual arithmetic mean	12 µg/m^3 [c,d]	• Prevention of excess deaths and illness from long-term exposures • Illnesses include respiratory symptoms, asthma exacerbation, and hospital admissions for cardiac and respiratory diseases	Gravimetric or Beta Attenuation

Pollutant	Source of Standard	Averaging Time	Concentration[a]	Basis of Standard	Method
				- Sensitive subpopulations include children, the elderly, and individuals with pre-existing cardiopulmonary disease (California Code of Regulations 1984)	
Ozone (O_3)	California	1-hr	0.09 ppm (180 µg/m^3)[c,e]	- Short-term exposures (1) 1-hr and multi-hour exposures: lung function decrements, and symptoms of respiratory irritation such as cough, wheeze, and pain upon deep inhalation (2) Multi-hour exposures: airway hyperreactivity and airway inflammation (3) Excess deaths, hospitalization, ER visits, asthma exacerbation, respiratory symptoms and restrictions in activity - Long-term exposures: tissue changes in the respiratory tract, decreased lung function, ER visits for asthma (California Code of Regulations 1984)	Ultraviolet Photometry
		8-hr	0.070 ppm (137 µg/m^3)[c,f]		
Carbon monoxide (CO)	California	1-hr	20 ppm (23 mg/m^3)	- Aggravation of angina pectoris and other aspects of coronary heart disease - Decreased exercise tolerance in persons with peripheral vascular disease and lung disease - Impairment of central nervous system functions - Possible increased risk to fetuses (California Code of Regulations 1984)	Non-Dispersive Infrared Photometry
		8-hr	9.0 ppm (10 mg/m^3)[g]		

Pollutant	Source of Standard	Averaging Time	Concentration[a]	Basis of Standard	Method
Hydrogen sulfide (H_2S)	California	1-hr	0.03 ppm (42 µg/m^3)	• Exceeds odor threshold (California Code of Regulations 1984)	Ultraviolet Fluorescence
Lead (Pb)	California	30-day average	1.5 µg/m^3	• Increased body burden • Impairment of blood formation and nerve conduction (California Code of Regulations 1984)	Atomic Absorption
	National	Rolling 3-month average over 3 years[h]	0.15 µg/m^3	• Neurological (including neurocognitive [IQ] and neurobehavioral effects), hematological, and immune effects in children • Hematological, cardiovascular, and renal effects in adults (US EPA 2008)	High Volume Sampler and Atomic Absorption

COPD, chronic obstructive pulmonary disease; ER, emergency room; IQ, intelligence quotient; $PM_{2.5}$, particulate matter of diameter less than 2.5 microns (µm)
*Particulate matter of diameter less than 10 microns (µm) (PM_{10}), sulfur dioxide, and nitrogen dioxide are also criteria air pollutants but were not monitored for in Lost Hills.

[a] Concentration expressed first in units in which it was promulgated. Equivalent units given in parentheses are based upon a reference temperature of 25°C and a reference pressure of 760 torr. Most measurements of air quality are to be corrected to a reference temperature of 25°C and a reference pressure of 760 torr; ppm in this table refers to ppm by volume, or micromoles of pollutant per mole of gas.

[b] The 24-hr $PM_{2.5}$ NAAQS is attained when 98 percent of the daily concentrations, averaged over three years, are equal to or less than the standard.

[c] California standards for ozone, carbon monoxide (except 8-hr Lake Tahoe), sulfur dioxide (1- and 24-hr), nitrogen dioxide, and particulate matter (PM_{10}, $PM_{2.5}$, and visibility reducing particles), are values that are not to be exceeded. All

others are not to be equaled or exceeded. California ambient air quality standards are listed in the Table of Standards in Section 70200 of Title 17 of the California Code of Regulations (1984).

[d] The "State Annual Average" for $PM_{2.5}$ is the average of the year's quarterly averages. The California annual standard is *exceeded* when the State Annual Average is greater than 12 µg/m^3 and is *violated* when the State Annual Standard Designation Value (the highest state annual average for three consecutive years) is greater than 12 µg/m^3. (CARB 2016b).

[e] The state 1-hr ozone standard is *exceeded* whenever the daily maximum 1-hr observation (after rounding to two decimal places) is greater than 0.09 ppm (CARB 2017b).

[f] The state 8-hr ozone standard is *exceeded* whenever the daily maximum 8-hr ozone average (after rounding to three decimal places) is greater than 0.070 ppm (CARB 2017a).

[g] Lake Tahoe has a special 8-hr Carbon Monoxide Standard of 6 ppm (7 mg/m^3).

[h] Averaging time is a rolling 3-month period with a maximum (not-to-be-exceeded) form, evaluated over a 3-year period (US EPA 2008 p. 66964).

e. References

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SNAPS Lost Hills Draft Final Report Appendices

I. Risk Assessment Results

The Study of Neighborhood Air near Petroleum Sources (SNAPS) air monitoring data for Lost Hills was used to conduct a human health risk assessment. The human health risk assessment characterized the potential health impacts, including cancer risk estimates, acute noncancer hazard quotients (HQs) and hazard indices (HIs), and chronic noncancer HQs and HIs. The report discussed the risk assessment results in section 4.3. This appendix provides more detailed tables and figures of results by chemical, organized by risk type.

a. Cancer Results

Table I.1. Cancer risk estimates for each individual carcinogen. Shown as cancer risk per million and percent (%) contribution to cumulative cancer risk. Compounds are arranged by cancer risk in decreasing order. Risks greater than one in a million are in bold. The cumulative cancer risk (710 per million) is determined by summing the risks for each individual carcinogen.

Compound	Detection frequency (%)	Cancer risk (per million)	% Contribution to cumulative cancer risk
Diesel PM	100[a]	**460**	65
Carbon tetrachloride	100	**67**	9.5
Formaldehyde	90	**66**	9.3
Benzene	90 (RT**)	**36**	5.1
Chromium VI	96[b]	**30**	4.2
Acetaldehyde	90	**19**	2.7
Arsenic	63	**17**	2.5
Nickel	78	**3.5**	0.49

Compound	Detection frequency (%)	Cancer risk (per million)	% Contribution to cumulative cancer risk
Styrene	76 (RT)	**3.2**	0.45
Isoprene^	37	**2.7**	0.38
Ethylbenzene	59 (RT)	**2.3**	0.32
Naphthalene	89	**1.2**	0.17
Hexachloroethane	25	**1.1**	0.15
Perchloroethylene	7	0.88	0.12
Isopropylbenzene*	12	0.52	0.073
Bis(2-ethylhexyl) phthalate	11	0.15	0.021
Lead	89	0.12	0.017

^Indicates that the health guidance value used to calculate risk for isoprene is a draft value and is under review by the California Scientific Review Panel on Toxic Air Contaminants.
*Indicates that the health guidance value used to calculate risk for isopropylbenzene was not derived by OEHHA.
**RT, real time data (some compounds were measured both in real time and in the laboratory; RT denotes that the real time data was used in the cancer health risk assessment)
[a]Based on black carbon.
[b]Based on total chromium.

b. Noncancer Results

Table I.2 Summary of acute and chronic hazard quotients (HQs) including the health guidance values (HGVs) and maximum/mean air concentrations. The intended exposure duration for the acute HGV and the duration of the maximum air sample used are also shown. Low DF (detection frequency) refers to compounds with <5% DF in real-time sampling or ≤1 detection over the reporting limit for discrete sampling; these compounds were not included in the chronic analysis.

Compound	CAS Registry Number	Acute HGV (µg/m^3)	Duration of HGV (hr)	Max Air Conc. (µg/m^3)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m^3)	Mean Air Conc. (µg/m^3)	Chronic HQ
Acetaldehyde	75-07-0	470	1	8.024	24	0.017	140	1.906	0.014
Acetone	67-64-1	20,000	24[b]	35.61	24	0.002	16,000	10.714	0.00067
Acetonitrile	75-05-8	590	1	2.685	24	0.0046	Low DF		
Acrolein	107-02-8	2.5	1	5.5	24	2.2	0.35	1.831	5.2
Aluminum	7429-90-5	No acute HGV					5	1.99	0.40
Antimony	7440-36-0	1	24[b]	0.0209	24	0.021	0.3	0.00707	0.024

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
Arsenic	7440-38-2	0.2	1	0.0229	24	0.11	0.015	0.00146	0.097
Barium	7440-39-3	No acute HGV					0.50	0.0499	0.10
Benzene	71-43-2	27	1	8.04	1	0.30	3	0.364	0.12
Benzoic acid	65-85-0	No acute HGV					0.7	0.102	0.15
Bis(2-ethylhexyl) phthalate	117-81-7	2	24[b]	0.065	24	0.03	1	0.018	0.02
n-Butane	106-97-8	220,000	1	784	1	0.0036	24,000	7.27	0.00030
1-Butene	106-98-9	62,000	1	0.807	1	0.000013	5,300	0.0287	0.0000054
cis-2-Butene	590-18-1	34,000	1	3.16	1	0.000093	Low DF		

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
trans-2-Butene	624-64-6	34,000	1	0.391	1	0.000012	Low DF		
Carbon tetrachloride	56-23-5	1,900	1	0.516	24	0.00027	40	0.45	0.011
Chromium III	16065-83-1	12	1	0.0508	24	0.0042	2	0.00581	0.0029
Chromium VI	18540-29-9	1.3	24	0.000513	24	0.00039	0.2	0.0000587	0.00029
Copper	7440-50-8	100	1	0.07	24	0.00070	1	0.0112	0.011
Cyclohexane	110-82-7	6,000	Chronic	8.34	24 rolling	0.001	6,000	0.808	0.00013
Cyclopentane	287-92-3	20,000	1	60.1	1	0.003	205	0.752	0.0037
n-Decane	124-18-5	5,800	1	2.29	1	0.00039	1,100	0.0846	0.000077

Compound	CAS Registry Number	Acute HGV (µg/m^3)	Duration of HGV (hr)	Max Air Conc. (µg/m^3)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m^3)	Mean Air Conc. (µg/m^3)	Chronic HQ
cis-1,3-Dichloropropene	10061-01-5 (542-75-6)	250	24	1.542	24	0.0062	Low DF		
trans-1,3-Dichloropropene	10061-02-6 (542-75-6)	250	24	0.998	24	0.0040	Low DF		
Diesel PM	N/A	No acute HGV					5	0.419	0.084
m-Diethylbenzene	141-93-5	30,000	24[b]	2	24 rolling	0.000067	34	0.407	0.012
p-Diethylbenzene	105-05-5	30,000	24[b]	1.94	24 rolling	0.000065	34	0.349	0.010
2,2-Dimethylbutane	75-83-2	19,000	1	6.86	1	0.00036	670	0.143	0.00021

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
2,3-Dimethylbutane	79-29-8	19,000	1	19.8	1	0.0010	670	0.428	0.00064
Dimethyl Disulfide	624-92-0	19	24	38.12	24	2.0	Low DF		
2,3-Dimethylpentane	565-59-3	34,000	1	17.9	1	0.00053	9,000	0.325	0.000036
2,4-Dimethylpentane	108-08-7	34,000	1	12.6	1	0.00037	9,000	0.151	0.000017
n-Dodecane	112-40-3	40,000	1	29.3	1	0.00073	Low DF		
Ethanol	64-17-5	6,270	1	18.64	24	0.0030	6,270	5.296	0.00084
Ethene	74-85-1	570,000	1	12.1	1	0.000021	6,100	0.277	0.000045

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
Ethylbenzene	100-41-4	20,000	24[b]	1.56	24 rolling	0.000078	2,000	0.265	0.00013
m-Ethyltoluene	620-14-4	20,000	24[b]	0.47	24 rolling	0.000024	2,000	0.117	0.000059
o-Ethyltoluene	611-14-3	20,000	24[b]	0.18	24 rolling	0.0000090	2,000	0.0406	0.000020
p-Ethyltoluene	622-96-8	20,000	24[b]	0.898	24 rolling	0.000045	2,000	0.0777	0.000039
Fluorene	86-73-7	No acute HGV					100	0.001	0.000010
Formaldehyde	50-00-0	55	1	6.95	24	0.13	9	3.142	0.35
Freon 11	75-69-4	No acute HGV					100	1.223	0.012
Freon 113	76-13-1	7,990	1	0.582	24	0.000073	6,230	0.489	0.0000785

Compound	CAS Registry Number	Acute HGV (µg/m^3)	Duration of HGV (hr)	Max Air Conc. (µg/m^3)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m^3)	Mean Air Conc. (µg/m^3)	Chronic HQ
Freon 12	75-71-8	20,000	24	2.619	24	0.0001	100	2.162	0.022
n-Heptane	142-82-5	34,000	1	26.3	1	0.00077	400	0.468	0.0012
Hexachloroethane	67-72-1	60,000	24[b]	0.11	24	0.0000018	30	0.028	0.00093
n-Hexane	110-54-3	19,000	1	91.2	1	0.0048	7,000	1.17	0.00017
Hydrogen Sulfide	7783-06-4	42	1	11.3	1	0.27	10	0.810	0.081
Isobutane	75-28-5	78,000	1	477	1	0.0061	24,000	4.46	0.00019
Isoprene	78-79-5	3,900	1	5.46	1	0.0014	390	0.144	0.00037
Isopropylbenzene	98-82-8	No acute HGV					400	0.0491	0.00012

Compound	CAS Registry Number	Acute HGV (µg/m^3)	Duration of HGV (hr)	Max Air Conc. (µg/m^3)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m^3)	Mean Air Conc. (µg/m^3)	Chronic HQ
Manganese	7439-96-5	5	24	0.513	24	0.10	0.09	0.0409	0.45
2-Methylbutane	78-78-4	200,000	1	371	1	0.0019	24,000	3.91	0.00016
Methylcyclohexane	108-87-2	9,000	1	78.1	1	0.009	3,000	1.52	0.0005
Methylcyclopentane	96-37-7	19,000	1	143	1	0.0075	7,000	1.88	0.0003
Methyl Ethyl Ketone	78-93-3	13,000	1	2.515	24	0.00019	5,000	0.661	0.00013
2-Methylheptane	592-27-8	19,000	1	8.15	1	0.00043	1,800	0.234	0.00013
3-Methylheptane	589-81-1	19,000	1	2.68	1	0.00014	1,800	0.0845	0.000047
2-Methylhexane	591-76-4	34,000	1	18.1	1	0.00053	9,000	0.33	0.000037

Compound	CAS Registry Number	Acute HGV ($\mu g/m^3$)	Duration of HGV (hr)	Max Air Conc. ($\mu g/m^3$)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV ($\mu g/m^3$)	Mean Air Conc. ($\mu g/m^3$)	Chronic HQ
3-Methylhexane	589-34-4	34,000	1	28.2	1	0.00083	9,000	0.452	0.000050
2-Methylnaphthalene	91-57-6	10,000	1	0.085	24	0.0000085	1	0.016	0.016
2-Methylpentane	107-83-5	19,000	1	89.3	1	0.0047	670	1.13	0.0017
3-Methylpentane	96-14-0	19,000	1	34.1	1	0.0018	670	0.612	0.00091
Naphthalene	91-20-3	204	1	0.039	24	0.000191	9	0.01	0.0011
Nickel	7440-02-0	0.2	1	0.0285	24	0.14	0.014	0.00382	0.27
n-Nonane	111-84-2	16,000	1	4.51	1	0.00028	20	0.147	0.0074

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
n-Octane	111-65-9	19,000	1	11.7	1	0.00062	1,800	0.268	0.00015
n-Pentane	109-66-0	200,000	1	302	1	0.0015	1,000	2.97	0.0030
1-Pentene	109-67-1	34,000	1	0.663	1	0.000020	Low DF		
cis-2-Pentene	627-20-3	34,000	1	0.627	1	0.000018	Low DF		
trans-2-Pentene	646-04-8	34,000	1	1.29	1	0.000038	Low DF		
Perchloroethylene	127-18-4	20,000	1	0.285	24	0.000014	35	0.042	0.0012
n-Propylbenzene	103-65-1	20,000	24[b]	2.04	24 rolling	0.00010	1,000	0.271	0.00027

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
Propylene	115-07-1	No acute HGV					3,000	0.0786	0.000026
Rubidium	7440-17-7	No acute HGV					1	0.00579	0.0058
Selenium	7782-49-2	No acute HGV					20	0.000424	0.000021
Strontium	7440-24-6	No acute HGV					2,000	0.0211	0.000011
Styrene	100-42-5	21,000	1	1.76	1	0.000084	900	0.123	0.00014
Tin	7440-31-5	No acute HGV					2	0.0107	0.0054
Toluene	108-88-3	5,000	1	16.2	1	0.0032	420	0.517	0.0012

Compound	CAS Registry Number	Acute HGV (µg/m³)	Duration of HGV (hr)	Max Air Conc. (µg/m³)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV (µg/m³)	Mean Air Conc. (µg/m³)	Chronic HQ
1,2,3-Trimethylbenzene	526-73-8	15,000	1	5.96	1	0.00040	60	0.304	0.0051
1,2,4-Trimethylbenzene	95-63-6	15,000	1	3.15	1	0.00021	60	0.179	0.0030
1,3,5-Trimethylbenzene	108-67-8	15,000	1	2.01	1	0.00013	60	0.0523	0.00087
2,2,4-Trimethylpentane	540-84-1	19,000	1	93.9	1	0.0049	1,800	1.46	0.00081
2,3,4-Trimethylpentane	565-75-3	19,000	1	2.9	1	0.00015	1,800	0.0815	0.000045
n-Undecane	1120-21-4	40,000	1	2.83	1	0.00007	Low DF		
Vanadium	7440-62-2	0.80	24[b]	0.0933	24	0.12	0.1	0.00891	0.089

Compound	CAS Registry Number	Acute HGV ($\mu g/m^3$)	Duration of HGV (hr)	Max Air Conc. ($\mu g/m^3$)	Duration of Max Air Sample[a] (hr)	Acute HQ	Chronic HGV ($\mu g/m^3$)	Mean Air Conc. ($\mu g/m^3$)	Chronic HQ
m/p-Xylene	1330-20-7	22,000	1	33.2	1	0.0015	700	0.319	0.00046
o-Xylene	95-47-6	22,000	1	11.4	1	0.00052	700	0.146	0.00021
Yttrium	7440-65-5	No acute HGV					0.1	0.00104	0.010
Zinc	7440-66-6	20	1	0.243	24	0.01	0.2	0.0343	0.2

Abbreviations: CAS, Chemical Abstracts Service; conc., concentration; max, maximum

[a] In order to have the most accurate comparison, HGVs were compared to the available maximum concentration most appropriate for the intended duration of the HGV. These include the 1-hr maximum measured for real-time samples, the maximum 24-hr average measured for discrete samples, or the maximum 24-hr rolling average for real-time samples.

[b] provisional-HGV (p-HGV) is based on Agency of Toxic Substance Disease Registry (ATSDR) acute minimal risk level (MRL), which is protective of exposures between 1 and 14 days (ATSDR 2018). These were noted as 24-hr durations because the sampling time used as a comparison was 24-hr.

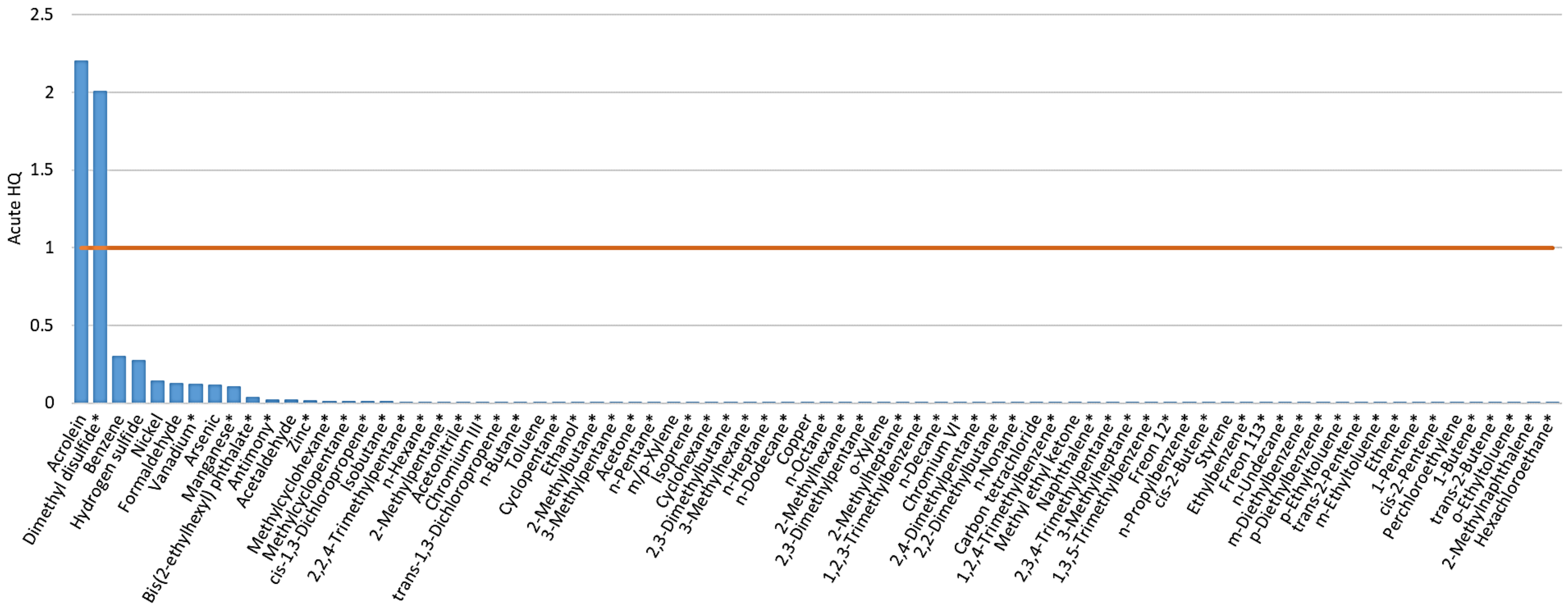


*Figure I.1 Acute hazard quotients (HQs) for 78 compounds measured during SNAPS air monitoring in Lost Hills. HQs are presented from highest to lowest. The orange horizontal line indicates an HQ of one, below which adverse health effects are not expected to occur. Trimethylbenzenes, xylenes, cis- and trans-2-butene, cis- and trans- 1,3,-dichloroprene have HGVs that were developed such that a mixture of isomers could be evaluated in place of the individual compound; the sum of the isomers' air concentrations all resulted in HQs below 1. *HGV is provisional (HGV is not an OEHHA acute REL).*

Table I.3 Acute hazard indices (HI) which combine hazard quotients (HQs) for compounds with the same target organ. An HI of less than or equal to one indicates that health effects in this target organ are not expected to occur. As the HQ increases above one, the probability of human health effects increases by an undefined amount. However, health protective assumptions are built in (e.g. maximum air concentrations are used in the acute evaluation) such that adverse outcomes may not occur event when the HI exceeds one. HIs that exceed 1 are in bold. HIs are presented from highest to lowest value.

Target Organ	HI
Respiratory system	**4.5**
Eyes	**2.4**
Immune system	0.45
Developmental	0.45
Nervous system	0.42
Hematological system	0.30
Cardiovascular system	0.12
Endocrine system	0.062
General toxicity	0.014
Skin	0.0030
Alimentary system	0.00029
Reproductive system	N/A*

*None of the compounds had the reproductive system as a target organ.

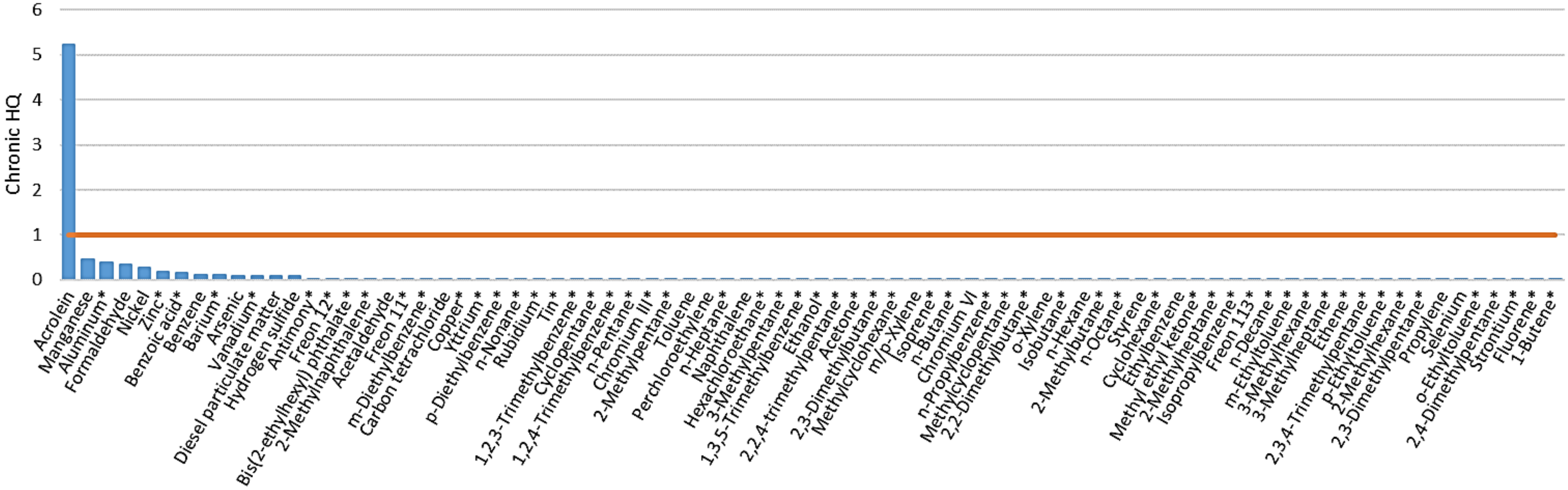


*Figure I.2 Chronic hazard quotients (HQs) for 80 compounds measured during SNAPS air monitoring in Lost Hills. HQs are presented from highest to lowest. The orange horizontal line indicates an HQ of one, below which health effects are not expected to occur. Trimethylbenzenes and xylenes have HGVs that were developed such that a mixture of isomers could be evaluated in place of the individual compound; the sum of the isomers' air concentrations all resulted in HQs below 1. *HGV is provisional (HGV is not an OEHHA chronic REL).*

Table I.4 Chronic hazard indices (HI) which combine hazard quotients (HQs) for compounds with the same target organ. An HI of less than or equal to one indicates that health effects in this target organ are not expected to occur. As the HQ increases above one, the probability of human health effects increases by an undefined amount. However, health protective assumptions are built in such that adverse outcomes may not occur event when the HI exceeds one. HIs that exceed 1 are in bold. HIs are presented from highest to lowest value.

Target Organ	HI
Respiratory system	**6.6**
Nervous system	**1.1**
Hematological system	0.41
Developmental	0.35
Skin	0.11
Cardiovascular System	0.097
General toxicity	0.039
Immune system	0.025
Alimentary system	0.020
Eyes	0.018

Endocrine system	0.00037
Bone and teeth	0.000011
Reproductive system	N/A*

*None of the compounds had the reproductive system as a target organ.

c. Comparisons of Acute/Chronic Air Concentrations and HQs between Lost Hills and various Locations in California

Several compounds had chronic or acute air concentrations that did not exceed the HGV but were within 10-fold of it (HQ less than or equal to 1 but greater than or equal to 0.1).

Regarding acute exposures, the seven compounds with air concentrations within 10-fold of their respective HGVs were arsenic, benzene, formaldehyde, hydrogen sulfide, manganese, nickel, and vanadium. The HQ values ranged from 0.10 to 0.30 (Table I.5). Compounds were detected at levels that fell within 10-fold of their HGV at frequencies of 19% for formaldehyde, and less than 1% for benzene (real-time samples) and hydrogen sulfide (real-time samples). For arsenic, manganese, nickel, and vanadium, one out of 46 samples was within 10-fold of the corresponding HGV. More information on these compounds is provided below in Table I.5.

The metals detected at levels within 10-fold of their acute HGV, had maximum concentrations detected during a wind event around October 30, 2019. The maximum concentrations of arsenic, magnesium, nickel, and vanadium were approximately 3- to 7-fold higher than the second highest value. The substantially higher concentrations measured during the wind event suggest that these metals were a component of wind-blown dust.

Regarding chronic exposures, the eight compounds with air concentrations within 10-fold of their respective chronic HGVs were aluminum, barium, benzene, benzoic acid, formaldehyde, manganese, nickel, and zinc. More information on these compounds is provided below in Table I.5.

Table I.5 Summary information for compounds with an acute or chronic hazard quotient (HQ) between 0.1 and 1 (1≥HQ≥0.1). The source of the HGV is provided along with potential sources of the compound in ambient air.

Compound (CAS Registry Number)	HQ	Source HGV	Potential Selected Sources in Ambient Air
Aluminum (7429-90-5)	Chronic HQ = 0.40	PPRTV chronic p-RfC	Naturally occurring, used in oil and gas development (Stringfellow et al. 2017b)
Arsenic (7440-38-2)	Acute HQ = 0.11	OEHHA acute REL	Naturally occurring, ore refining, pesticides, wood preservatives (OEHHA 2008)
Barium (7440-39-3)	Chronic HQ = 0.10	HEAST chronic RfC	Naturally occurring, used in routine oil and gas production (ATSDR 2007; OEHHA 2003; Stringfellow et al. 2017b)
Benzene (71-43-2)	Acute HQ = 0.30	OEHHA acute REL	Combustion of fossil fuels, naturally occurring in oil and gas, part of drilling fluids (Garcia-Gonzales et al. 2019; OEHHA 2008)
	Chronic HQ = 0.12	OEHHA chronic REL	
Benzoic acid (65-85-0)	Chronic HQ = 0.15	PPRTV subchronic p-RfC	Emitted in vehicle exhaust, industrial sources, pesticides, used in well stimulation, used in food processing (CalGEM 2021; DPR 2019; US EPA 2005; WHO 2000)

Compound (CAS Registry Number)	HQ	Source HGV	Potential Selected Sources in Ambient Air
Formaldehyde (50-00-0)	Acute HQ = 0.13	OEHHA acute REL	Ubiquitous in air, secondary air pollutant, combustion of fossil fuels, oil refining, emitted from oil field equipment, contained in well stimulation compounds, used in routine oil and gas development (CalGEM 2021; Garcia-Gonzales et al. 2019; OEHHA 2008; Stringfellow et al. 2017a; Stringfellow et al. 2017b)
	Chronic HQ = 0.35	OEHHA chronic REL	
Hydrogen sulfide (7783-06-4)	Acute HQ = 0.27	OEHHA acute REL	Naturally occurring in crude oil and natural gas, petroleum and gas processing, sewage treatment plants, swine containment and manure-handling operations, pulp and paper operations (ATSDR 2016)
Manganese (7439-96-5)	Acute HQ = 0.10	TCEQ acute ReV (24 hr)	Naturally occurring, combustion of gasolines with manganese-containing octane enhancer, pesticides (OEHHA 2008)
	Chronic HQ = 0.45	OEHHA chronic REL	
Nickel (7440-02-0)	Acute HQ = 0.14	OEHHA acute REL	Naturally occurring, combustion of fossil fuels, associated with petroleum processing and oil field emissions (OEHHA 2008; OMNI and DRI 1989; STI 2015)
	Chronic HQ = 0.27	OEHHA chronic REL	

Compound (CAS Registry Number)	HQ	Source HGV	Potential Selected Sources in Ambient Air
Vanadium (7440-62-2)	Acute HQ = 0.12	ATSDR acute MRL	Naturally occurring, oil refineries, combustion of coal and residual fuel oils, oil field emissions (ATSDR 2012; OMNI and DRI 1989)
Zinc (7440-66-6)	Chronic HQ = 0.17	DFG MAK	Naturally occurring, forest fires, mining, zinc production facilities, processing of zinc-bearing raw materials (e.g., lead smelters), brass works, coal and fuel combustion, refuse incineration, iron and steel production (ATSDR 2005)

Abbreviations: ATSDR, Agency for Toxic Substances and Disease Registry; CAS, Chemical Abstracts Service; DFG MAK, Deutsche Forschungsgemeinschaft maximum workplace concentration; HEAST, Health Effects Assessment Summary Tables; MRL, Minimal Risk Level; OEHHA, Office of Environmental Health Hazard Assessment; PPRTV, Provisional Peer-Reviewed Toxicity Value; p-RfC, Provisional Reference Concentration; REL, Reference Exposure Level; ReV, Reference Values; TCEQ, Texas Commission on Environmental Quality;

i. Maximum Air Concentrations and Acute HQs at various Locations in California

Compounds with an acute HQ greater than or equal to 0.1, but less than or equal to 1, with data in Internet Aerometric Data Analysis & Management (iADAM) (2016-2019; CARB 2021) were compared across various Central Valley air monitoring sites (Table I.5; Figure I.3). Notably, acute health effects would not be anticipated as a result of any of these exposures as the HQs are less than one. In order to characterize high air concentrations at various locations, the acute HQ was calculated with the 90th percentile and maximum air concentration. As discussed in report Section 3.4.2, the maximum concentrations for arsenic, manganese, nickel, and vanadium occurred during a wind event (measured on October 30, 2019). This is likely why the acute HQs calculated with the maximum air concentration were substantially higher in Lost Hills than for the other locations for these compounds. Using the 90th percentile air concentration in the calculation of acute HQs resulted in acute HQs which were more similar across these locations (Figure I.3). For the metals, the methods used to collect and analyze the filter samples are not the same between the iADAM data (inductively coupled plasma mass spectrometry [ICP-MS]) and Lost Hills (x-ray fluorescence [XRF]), and values from the two techniques may not be always comparable. Thus, this comparison should be considered qualitative. Formaldehyde and benzene, on the other hand, were analyzed using essentially identical methods to those used for Lost Hills. The Lost Hills formaldehyde acute HQs are on the lower end of the range observed at the other locations, and the Lost Hills benzene acute HQs are lower than that of all of the other locations (Figure I.3).

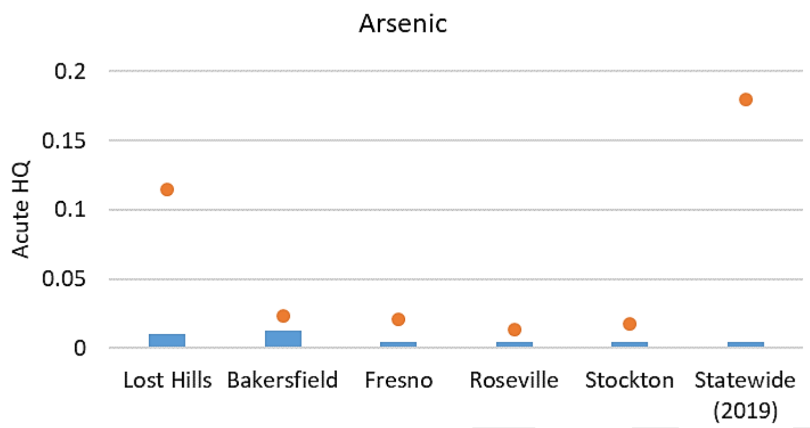
The benzene discrete sample maximum was used in this analysis so that the methods more closely align with the other locations. The real-time benzene air concentration maximum results in an acute HQ of 0.30, which is higher than the other locations but lower than statewide. It is expected that the real-time maximum would be higher than the discrete maximum and it is likely that would be true at the other locations if that type of sampling was performed.

A 2012-2013 air monitoring study of the Inglewood Oil Field by Baldwin Hills reported maximum concentrations for metals and other compounds (STI 2015). Regarding metals, the Lost Hills maximum concentration was measured during a wind event, thus, the second highest concentration was compared to the Baldwin Hills maximum concentration. Using the second highest Lost Hills values, arsenic was similar between the locations, manganese and vanadium were higher in Lost Hills, and nickel was lower in Lost Hills. In the Baldwin Hills study, only one nickel 1-hr sample exceeded the acute REL but the authors indicated that, based on wind direction, it did not originate from the Oil Field. The authors noted "[Inglewood] Oil Field operations were associated with potential increases in nickel and manganese concentrations" based on positive matrix factorization analysis (STI 2015 p. ES-3). However, nickel and manganese contributions from the Inglewood Oil Field were not quantified because they were below the level of concern. Comparisons are qualitative because of methodological differences including continuous sized filtered sampling in the

Baldwin Hills study compared to discrete sampling on total suspended particulate in Lost Hills.

Benzene was not considered to have an acute risk in the Baldwin Hills study. The authors noted that Inglewood Oil Field operations were associated with transient increases in benzene, specifically drilling operations. The Lost Hills real-time maximum benzene concentration was higher than Baldwin Hills, albeit sampling in Baldwin Hills was for two weeks compared to 11 months in Lost Hills. Comparisons are qualitative because of methodological differences including the use of proton transfer reaction time of flight mass spectrometer for real-time monitoring in Baldwin Hills whereas real-time benzene monitoring in Lost Hills was completed using in-situ thermal desorption gas chromatography-flame ionization detection.

Hydrogen sulfide can be compared to other California monitors. The California Air Resource Board (CARB) monitors for hydrogen sulfide at 14 monitors, all of which are located near a local source such as an oil or gas processing facility, refinery, or geothermal field. Data for the years 2018 through 2020 were analyzed and available for 13 of these monitors (CARB 2021). High-end concentrations were largely similar to those in Lost Hills, with 90th percentile values for 12 of 13 monitors ranging from 0.8 to 4.1 µg/m^3, within two-fold of the Lost Hills 90th percentile (1.8 µg/m^3). The monitor at Trona near the Coso Hot Springs geothermal field stood out with a 90th percentile concentration of 17 µg/m^3. The corresponding acute HQ values would also be within two-fold of that for Lost Hills (acute HQ = 0.04 at 90th percentile of 1.8 µg/m^3) and are all at an HQ of 0.1 or less except for Trona at an HQ of 0.39. None of the values exceed one and therefore adverse health effects are not anticipated at the 90th percentile concentrations.


Arsenic
Acute HQ
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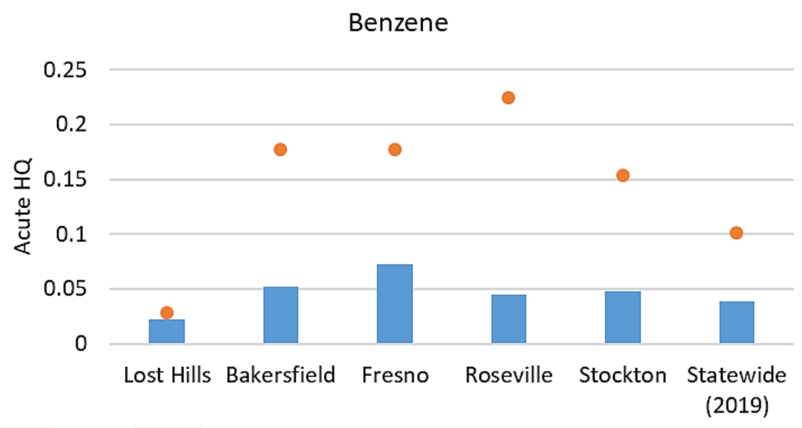
0.15
0.1
0.05
0
Lost Hills
Bakersfield
Fresno
Roseville
Stockton
Statewide (2019)


Benzene
Acute HQ
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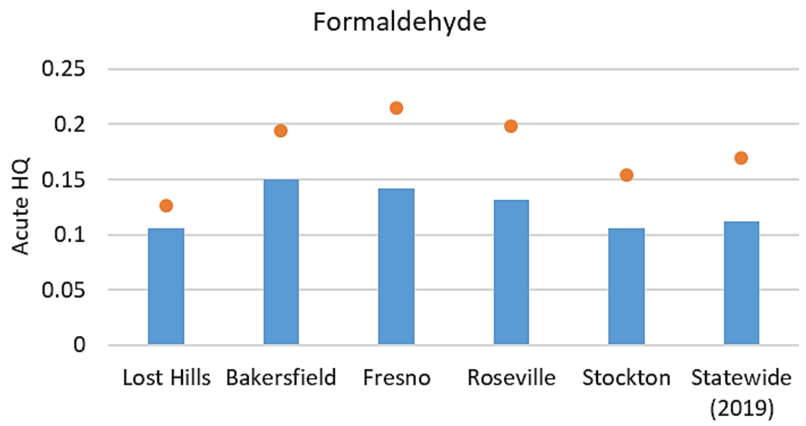
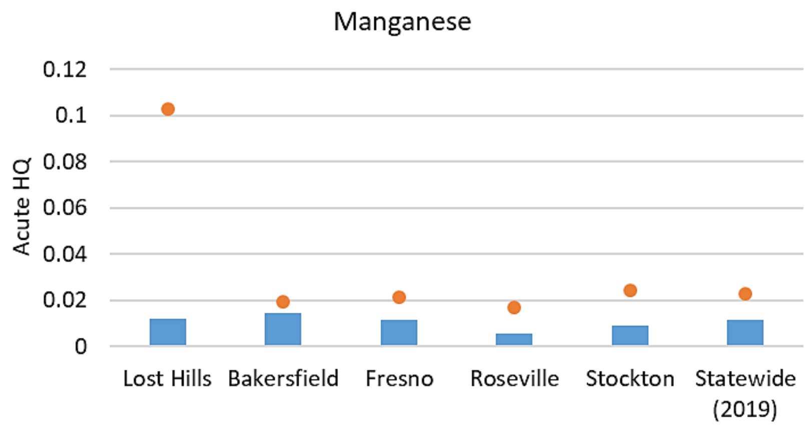
0.2
0.15
0.1
0.05
0
Lost Hills
Bakersfield
Fresno
Roseville
Stockton
Statewide (2019)


Formaldehyde
Acute HQ
0.25
0.2
0.15
0.1
0.05
0
Lost Hills
Bakersfield
Fresno
Roseville
Stockton
Statewide (2019)


Manganese
Acute HQ
0.12
0.1
0.08
0.06
0.04
0.02
0
Lost Hills
Bakersfield
Fresno
Roseville
Stockton
Statewide (2019)

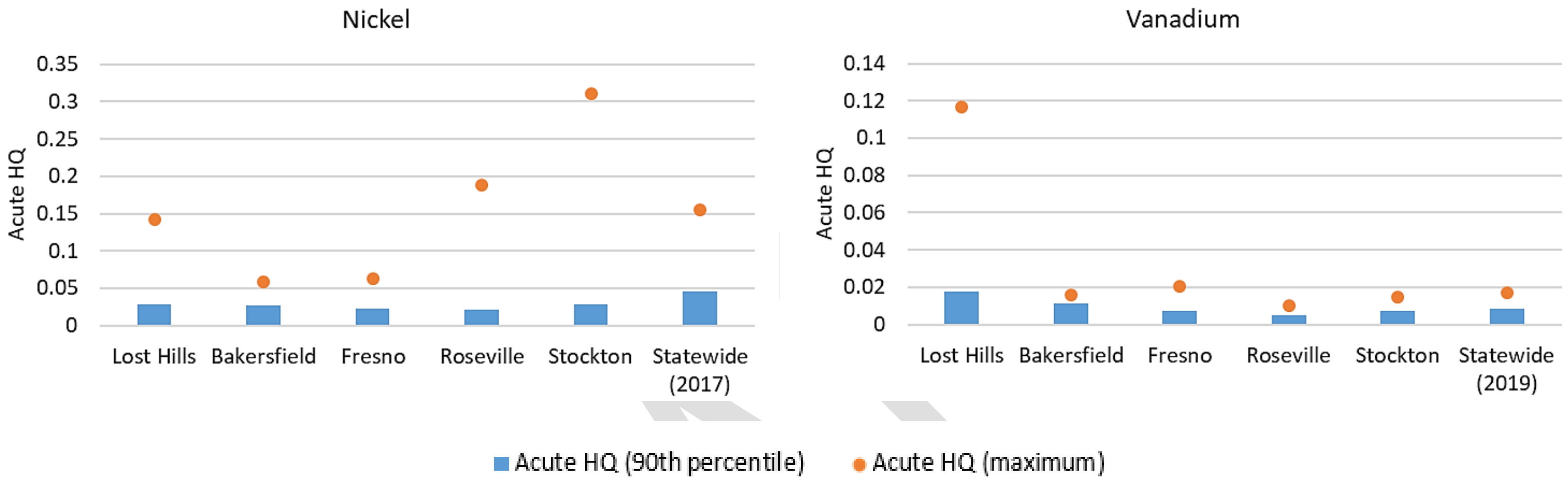


Figure I.3 Acute hazard quotients (HQs) calculated using the 90th percentile and maximum air concentrations in Lost Hills, at regional sites in the Central Valley, and statewide for arsenic, benzene, formaldehyde, manganese, nickel and vanadium. Benzene discrete sample data from Lost Hills were used in this analysis so that sampling/methods more closely align with the other locations. Lost Hills data are from SNAPS monitoring during 2019-20. Data for other regional sites are from the iADAM dataset for monitoring 2016-2019 (CARB 2021). Statewide 90th percentiles and maximums were taken from the most recent year with complete data (that is, an average was calculated in iADAM); this was 2019 for all compounds expect nickel which was 2017.

ii. Average Air Concentrations and Chronic HQs at various Locations in California

Compounds with a chronic HQ greater than or equal to 0.1, but less than or equal to 1, with data in iADAM (2016-2019; CARB 2021) were compared across various Central Valley air monitoring sites (Table I.5; Figure I.4). Notably, chronic health effects would not be anticipated as a result of any of these exposures as the HQs are less than one. As Figure I.4 demonstrates, a qualitative comparison of the HQs for manganese, nickel, and zinc indicates that the Lost Hills HQs are similar to those determined for other Central Valley locations. For the metals, the methods used to collect and analyze the filter samples are not the same between the iADAM data (ICP-MS) and Lost Hills (XRF), and values from the two techniques may not be always comparable. Thus, this comparison should be considered qualitative. Formaldehyde and benzene, on the other hand, were analyzed using nearly identical methods to those used for Lost Hills. The Lost Hills formaldehyde HQ is on the lower end of the range observed at the other locations, and the Lost Hills benzene HQ is lower than that of all of the other locations. Benzene and formaldehyde have been identified as risk drivers in other risk assessments of places near oil and gas extraction, albeit, like in this assessment, they did not always exceed the HGV (CDPHE 2007, 2010; Holder et al. 2019; Long et al. 2019; McKenzie et al. 2012; McMullin et al. 2018; PA DEP 2018; TCEQ 2010).

A 2012-2013 air monitoring study of the Inglewood Oil Field by Baldwin Hills (STI 2015) was compared to Lost Hills air monitoring data, specifically, the reported median concentrations for metals and average concentrations for benzene. All of the median metal values were higher in Lost Hills than Baldwin Hills. For nickel and vanadium, the Baldwin Hills median appears to be below the method detection limit. It is not clear if the difference between median metal concentrations is due to methodological differences or a difference in air quality. Because of the methodological differences discussed in Appendix I Section c.i., all comparisons are qualitative. The average real-time benzene concentration measured in Lost Hills was lower than the two-week average concentration measured in Baldwin Hills.

Barium did not have recent data in the iADAM database (CARB 2021). The statewide average for barium ranged from 0.0267 - 0.0508 μg/m^3 for the years 1991 – 2002, similar to the Lost Hills average of 0.0499 μg/m^3. For the most recent year available (2002), the average was 0.0508 μg/m^3 which would result in a chronic HQ of 0.10, similar to the Lost Hills HQ of 0.10. The Lost Hills value is also consistent with barium levels in ambient air typically being ≤0.05 μg/m^3 (WHO 1991). The methods used for the latter estimate were not documented, thus, the methods have not been compared to SNAPS methodology and the comparison is qualitative.

Benzoic acid is not in the iADAM database (CARB 2021). Qualitatively, the average air concentration in Lost Hills (0.102 μg/m^3) could be compared to older values in Pasadena, CA (0.09-0.38 μg/m^3) and Los Angeles (0.005-0.13 μg/m^3), which are both similar to Lost Hills (Kawamura et al. 1985; Schuetzle et al. 1975, as cited by WHO 2000). The methods used in these analyses have not been compared to SNAPS methodology, thus, this comparison is qualitative.

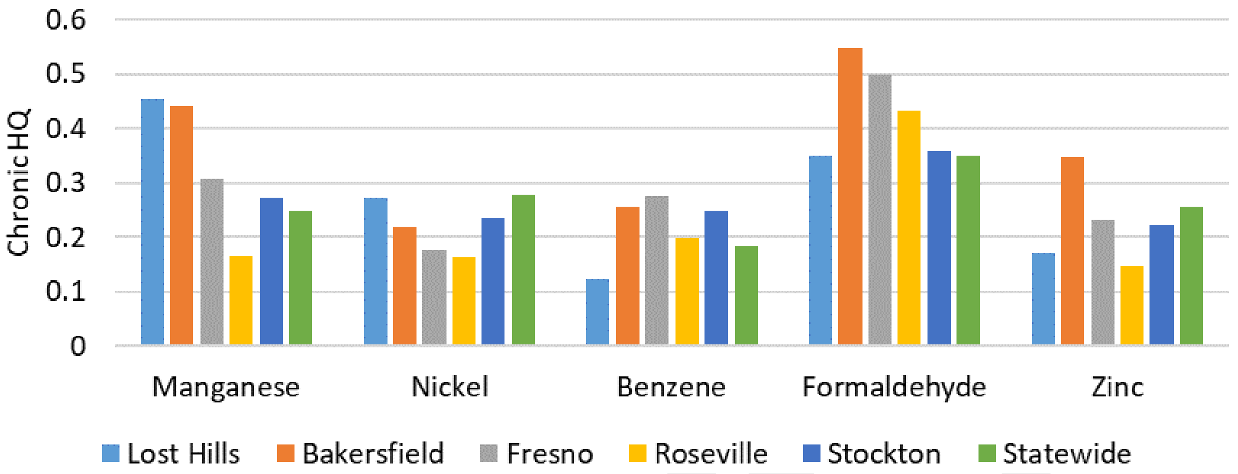


Figure I.4 Chronic hazard quotients (HQs) in Lost Hills, at regional sites in the Central Valley, and statewide for manganese, nickel, benzene, formaldehyde, and zinc. Benzene discrete sample data from Lost Hills were used in this analysis so that sampling/methods most closely align with the other locations. Lost Hills data are from SNAPS monitoring during 2019-20. Data for other regional sites (2016-2019) and statewide are from the iADAM dataset (CARB 2021). Statewide averages were taken from the most recent year with complete data (that is, an average was calculated in iADAM); this was 2017 for nickel and 2019 for all other compounds.

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SNAPS Lost Hills Draft Final Report Appendices

J. Health Risk Assessment: Additional Analyses

This appendix discusses methods used to address several specific challenges in the assessment:

- Some of the health guidance values (HGVs) used in the health risk assessment were developed for the oral route of exposure. These were extrapolated to the inhalation route for this assessment. To ensure that any respiratory sensitization potential was not overlooked, these compounds were screened for potential for respiratory sensitization based on chemical structure using computationally-based (*in silico)* methods (Section a).
- Some compounds were detected in 24-hr samples but the acute HGV for the compound was intended for a 1-hr exposure duration and the potential to underestimate the acute HQ is highlighted (Section b).
- The metal concentration data was analyzed to determine possible sources of the detected metals (Section c).

a. Respiratory Sensitization *in silico* Screening

Allergic sensitization of the respiratory tract is a heightened response to a compound from prior exposure resulting in an allergic-type reaction (e.g., asthma, rhinitis) which can occur in a subset of exposed individuals. Respiratory sensitization develops after an induction phase where initial exposure to the compound triggers the immune system, followed by an elicitation phase where re-exposures causes an allergic response (Cochrane et al. 2015). Induction and elicitation are considered threshold mechanisms but the threshold for elicitation is typically lower than induction (Cochrane et al. 2015). Specifically, elicitation (allergic) reactions can happen at low concentrations that would not affect non-sensitized individuals.

There are no generally-accepted methods to identify respiratory sensitizers (Arts 2020; Chary et al. 2018; Dik et al. 2016). In this assessment, the potential for compounds with an oral HGV based on oral toxicity data to be respiratory sensitizers was assessed using computer models that predict respiratory sensitization risk based on the compound's chemical structure. This is a screening-level approach as computer models on their own are not sufficient for classification of respiratory sensitizers due to limitations (e.g., computer models are only as good as the chemical database they rely on) (Arts 2020).

The CAS Registry Numbers for detected compounds with oral HGVs based on oral data were profiled using the Organization for Economic Co-operation and Development Quantitative Structure-Activity Relationship (OECD QSAR) Toolbox (OECD QSAR Toolbox version 4.4.1; OECD 2020). The respiratory sensitization profiler is described by the toolbox as "intended to be used for the assessment of respiratory sensitisation potential of low molecular weight chemicals. The profiler has been developed from mechanistic knowledge of the elicitation phase of respiratory sensitisation, thus identifies chemicals able to covalently bind to proteins in the lung" (OECD 2020). The compounds in this assessment for which the provisional health guidance value (p-HGV) was based on an oral HGV with underlying oral data (bis(2-ethylhexyl)phthalate, fluorene, rubidium, and strontium) did not have any alerts for respiratory sensitization in the Toolbox.

The mode of action for respiratory sensitization mirrors that of skin sensitization including covalent binding to proteins leading to immune response (Arts 2020; Chary et al. 2018). Thus, OECD QSAR Toolbox profilers for direct peptide reactivity (DPRA), protein binding, and skin sensitization (which generally has a larger chemical database than respiratory sensitization) were also explored (Profilers: Protein binding potency h-CLAT, Protein binding alerts for skin sensitization according to GHS, Protein binding alerts for skin sensitization by OASIS, Protein binding by OASIS, Protein binding by OECD, Protein binding potency Cys [DPRA 13%], Protein binding potency Lys [DPRA 13%], Skin sensiti[z]ation for DASS). None of the compounds had any alerts (bis(2-ethylhexyl)phthalate, fluorene, rubidium, strontium).

There is significant uncertainty in using computer models to predict health outcomes and there may be more uncertainty with metals for which similar compounds can have very different properties. The computer models do not predict that bis(2-ethylhexyl)phthalate, fluorene, rubidium, or strontium are respiratory sensitizers. Lastly, a PubMed database search on these compounds and respiratory or skin sensitization did not result in the identification of relevant publications suggesting that they are respiratory sensitizers. However, exposure to bis(2-ethylhexyl)phthalate (including prenatally) has been associated with asthma and allergy in epidemiological studies (Wang et al. 2019). This would need to be considered in development of an inhalation-specific HGV for bis(2-ethylhexyl)phthalate.

b. Compounds for which Acute HGV Duration (1-hr Average) Did Not Match Sample Duration (24-hr Average)

In the acute analysis, the maximum air concentration sampling time and the HGV's intended exposure duration were matched when feasible (Appendix I, Table I.2). As such, if a real-time sample had an acute HGV intended for a 1-hr exposure then the 1-hr maximum was used; if a real-time sample had an acute HGV intended for a 24-hr exposure then the 24-hr rolling maximum was used; and if a 24-hr sample had an acute HGV intended for a 24-hr exposure then the 24-hr sample maximum was used. There were 16 compounds with 24-hr samples where the available acute HGV was intended for a 1-hr exposure duration (Table J.1). It is generally held that as the averaging time for air sampling increases, the maximum concentration decreases (Barratt 2001). Thus, the maximum 24-hr concentration is likely an underestimate of the maximum 1-hr concentration and the acute hazard quotients (HQs) are also likely to be an underestimate.

Table J.1 Compounds measured over 24 hr where the HGV is intended to protect for a 1-hr exposure and HQs are likely to be an underestimate.

Compounds	CAS Registry Number	Type of max (hr)	HGV exposure duration (hr)	HQ
2-Methylnaphthalene	91-57-6	24	1	0.0000085
Acetaldehyde	75-07-0	24	1	0.017
Acetonitrile	75-05-8	24	1	0.0046
Acrolein	107-02-8	24	1	**2.2**
Arsenic	7440-38-2	24	1	0.11
Carbon tetrachloride	56-23-5	24	1	0.00027
Chromium III	16065-83-1	24	1	0.0042
Copper	7440-50-8	24	1	0.00070
Ethanol	64-17-5	24	1	0.0030
Formaldehyde	50-00-0	24	1	0.13
Freon 113	76-13-1	24	1	0.000073
Methyl ethyl ketone	78-93-3	24	1	0.00019
Naphthalene	91-20-3	24	1	0.00019
Nickel	7440-02-0	24	1	0.14
Perchloroethylene	127-18-4	24	1	0.000014

Zinc	7440-66-6	24	1	0.012

Abbreviations: CAS, Chemical Abstracts Service

c. Elemental Source Attribution

i. Relationship Between Elemental Concentrations and Wind Speed

One way to explore possible sources of the detected elements is to compare the concentrations observed during high wind days to concentrations on low wind days. High winds are expected to increase concentrations of those elements of primarily crustal origin (windblown dust). In the case of point sources of metal emissions, high winds may help disperse and dilute particles, reducing air concentrations near sources, while low winds may leave high concentrations near sources. Figure J.1 shows the ratio between the average concentrations for days when the 24-hr average wind speed was above (16 days) versus below (30 days) the average 24-hr wind speed of the study (1.7 miles per hour [mph]). For most of the elements, concentrations are higher on the days with stronger winds, including the typical crustal metals silicon, aluminum, calcium, and iron. The crustal metals, so-named because they are among the most abundant in the Earth's crust (≥ 0.1% by weight), include aluminum, calcium, iron, magnesium, potassium, sodium, silicon, and titanium (note that magnesium and sodium were not measured in the Study of Neighborhood Air near Petroleum Sources (SNAPS) study) (UC Riverside 1996). The compounds that were not enriched during higher wind days include chlorine, tin, bromine, antimony, lead, and selenium. The ratios for these six compounds are less than 1, indicating that the concentrations of these compounds tended to be *lower* when the wind was stronger, possibly suggesting a distinct, non-crustal source. Parsing the data by wind direction (east-west, upwind-downwind of the Oil Field) was not feasible because the 24-hr average wind (and high winds) was almost always from the west. While Figure J.1 gives an indication of which elements may be associated with windblown dust, there may be confounding factors, such as correlation between when the winds are highest and when certain metals are more likely to be present.

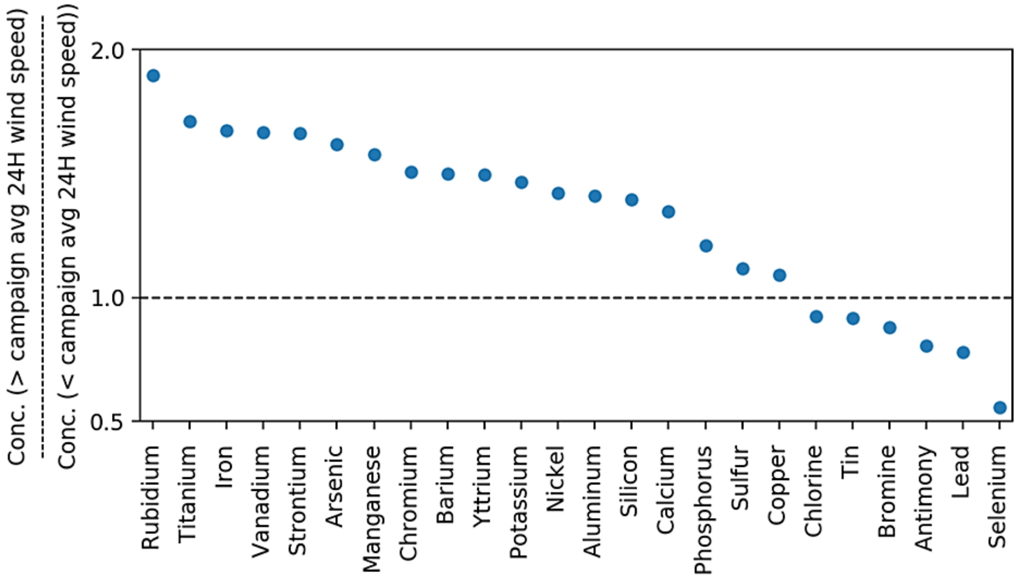
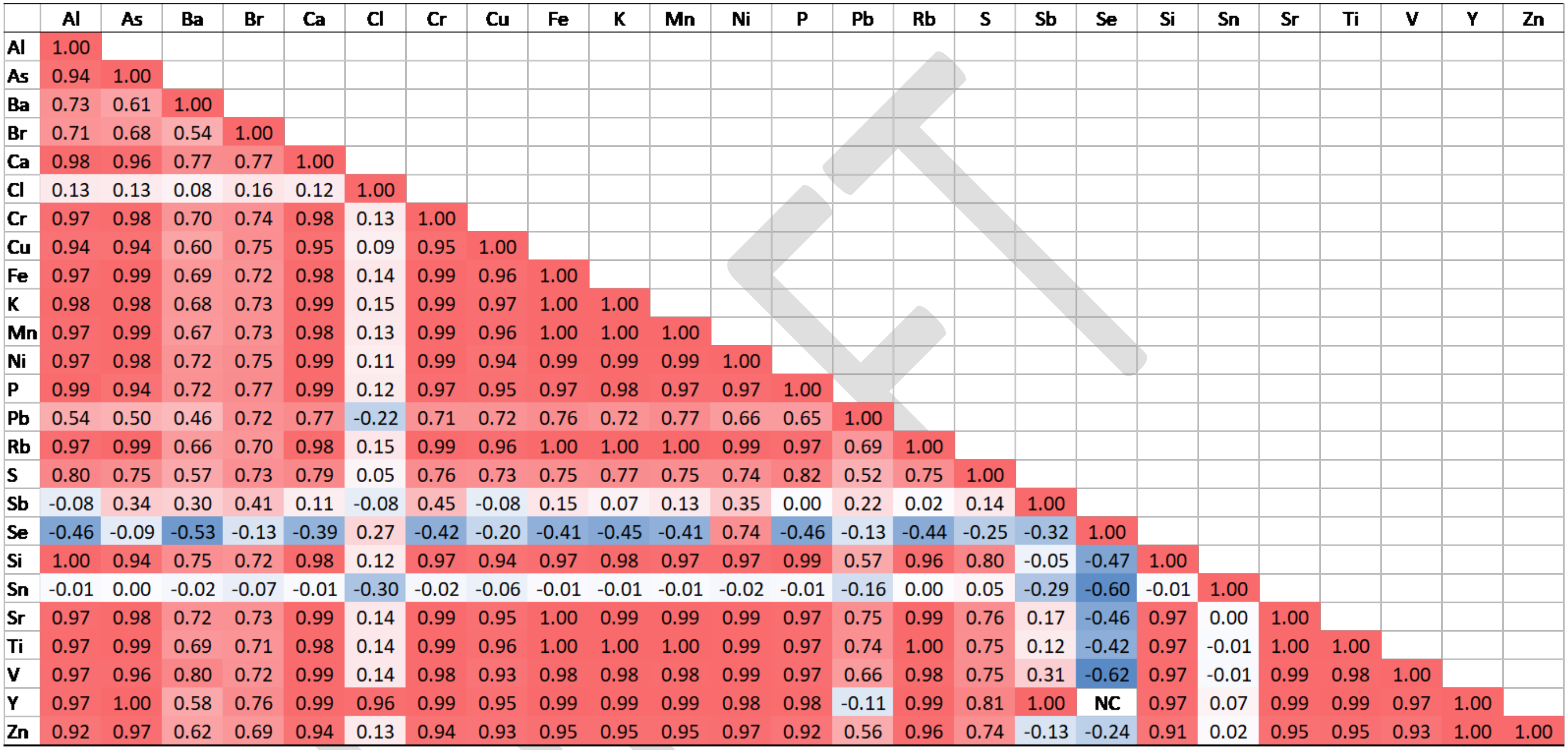


Figure J.1 Ratios between average elemental concentrations for days on which the 24-hr average wind speed was above (16 days) versus below (30 days) the 24-hr average wind speed during the study (1.7 mph). A ratio of 1.0, indicating the average concentration was the same on the high wind days as it was on the low wind days, is shown as a dotted horizontal line.

ii. Elemental Correlations

Possible sources of the detected elements (e.g., crustal versus anthropogenic) were also explored via correlation coefficients between the various elemental concentrations (correlations determined in Excel). The concentrations measured above the reporting limit (RL) at each sampling date served as the input data (thus values <RL were excluded from the correlation calculation). Results are shown in Figure J.2.

As evident in the correlation matrix, the measured concentrations of most elements are strongly positively correlated with each other (darker red shading). Exceptions are chlorine (detection frequency [DF] 100%), antimony (DF 30%), tin (DF 72%), and selenium (DF 26%). Interestingly, antimony was highly correlated only with yttrium (R=1.00), but this is based on only three data points (three of 46 sampling dates had levels >RL for both compounds). Chlorine was also highly correlated only with yttrium (R = 0.96) (based on 11 data points). Tin was not highly correlated with any other element, with the strongest correlation being -0.60 with selenium. The lack of strong correlation between chlorine, antimony, and tin and most of the other elements, particularly the crustal elements, may indicate that these compounds come from an anthropogenic or natural source (described in the next section) rather than windblown dust. Interestingly, selenium is negatively correlated with all but two compounds, chlorine (R = 0.27) and nickel (R = 0.74). The negative correlations may point to a source for selenium distinct from the source of the rest of the compounds, while the strong correlation with nickel suggests a common source for selenium and nickel.



	Al	As	Ba	Br	Ca	Cl	Cr	Cu	Fe	K	Mn	Ni	P	Pb	Rb	S	Sb	Se	Si	Sn	Sr	Ti	V	Y	Zn
Al	1.00																								
As	0.94	1.00																							
Ba	0.73	0.61	1.00																						
Br	0.71	0.68	0.54	1.00																					
Ca	0.98	0.96	0.77	0.77	1.00																				
Cl	0.13	0.13	0.08	0.16	0.12	1.00																			
Cr	0.97	0.98	0.70	0.74	0.98	0.13	1.00																		
Cu	0.94	0.94	0.60	0.75	0.95	0.09	0.95	1.00																	
Fe	0.97	0.99	0.69	0.72	0.98	0.14	0.99	0.96	1.00																
K	0.98	0.98	0.68	0.73	0.99	0.15	0.99	0.97	1.00	1.00															
Mn	0.97	0.99	0.67	0.73	0.98	0.13	0.99	0.96	1.00	1.00	1.00														
Ni	0.97	0.98	0.72	0.75	0.99	0.11	0.99	0.94	0.99	0.99	0.99	1.00													
P	0.99	0.94	0.72	0.77	0.99	0.12	0.97	0.95	0.97	0.98	0.97	0.97	1.00												
Pb	0.54	0.50	0.46	0.72	0.77	-0.22	0.71	0.72	0.76	0.72	0.77	0.66	0.65	1.00											
Rb	0.97	0.99	0.66	0.70	0.98	0.15	0.99	0.96	1.00	1.00	1.00	0.99	0.97	0.69	1.00										
S	0.80	0.75	0.57	0.73	0.79	0.05	0.76	0.73	0.75	0.77	0.75	0.74	0.82	0.52	0.75	1.00									
Sb	-0.08	0.34	0.30	0.41	0.11	-0.08	0.45	-0.08	0.15	0.07	0.13	0.35	0.00	0.22	0.02	0.14	1.00								
Se	-0.46	-0.09	-0.53	-0.13	-0.39	0.27	-0.42	-0.20	-0.41	-0.45	-0.41	0.74	-0.46	-0.13	-0.44	-0.25	-0.32	1.00							
Si	1.00	0.94	0.75	0.72	0.98	0.12	0.97	0.94	0.97	0.98	0.97	0.97	0.99	0.57	0.96	0.80	-0.05	-0.47	1.00						
Sn	-0.01	0.00	-0.02	-0.07	-0.01	-0.30	-0.02	-0.06	-0.01	-0.01	-0.01	-0.02	-0.01	-0.16	0.00	0.05	-0.29	-0.60	-0.01	1.00					
Sr	0.97	0.98	0.72	0.73	0.99	0.14	0.99	0.95	1.00	0.99	0.99	0.99	0.97	0.75	0.99	0.76	0.17	-0.46	0.97	0.00	1.00				
Ti	0.97	0.99	0.69	0.71	0.98	0.14	0.99	0.96	1.00	1.00	1.00	0.99	0.97	0.74	1.00	0.75	0.12	-0.42	0.97	-0.01	1.00	1.00			
V	0.97	0.96	0.80	0.72	0.99	0.14	0.98	0.93	0.98	0.98	0.98	0.99	0.97	0.66	0.98	0.75	0.31	-0.62	0.97	-0.01	0.99	0.98	1.00		
Y	0.97	1.00	0.58	0.76	0.99	0.96	0.99	0.95	0.99	0.99	0.99	0.98	0.98	-0.11	0.99	0.81	1.00	**NC**	0.97	0.07	0.99	0.99	0.97	1.00	
Zn	0.92	0.97	0.62	0.69	0.94	0.13	0.94	0.93	0.95	0.95	0.95	0.97	0.92	0.56	0.96	0.74	-0.13	-0.24	0.91	0.02	0.95	0.95	0.93	1.00	1.00

Figure J.2 Correlation matrix between elemental concentrations measured in Lost Hills air. Pearson correlation coefficient (R) values are shaded red for positive correlations, white for correlations near zero, and blue for negative correlations, with darker colors indicating a stronger correlation (closer to 1 or -1). NC = not calculated (n=2 sampling dates where both Y and Se were detected). Abbreviations: Al, aluminum; As, arsenic; Ba, barium; Br, bromine; Ca, calcium; Cl, chlorine; Cr, chromium; Cu, copper; Fe, iron; K, potassium; Mn, manganese; Ni, nickel; P, phosphorus; Pb, lead; Rb, rubidium; S, sulfur; Sb, antimony; Se, selenium; Si, silicon; Sn, tin; Sr, strontium; Ti, titanium; V, vanadium; Y, yttrium; Zn, zinc.

iii. Elemental Enrichment Factor Analysis

1. Methods

An elemental enrichment factor (EF) analysis was also performed to delineate possible sources of the detected elements. The analysis was performed using the following equation:

$$EF = \frac{\left(X_{Air} / R_{Air} \right)}{\left(X_{Crust} / R_{Crust} \right)}$$

Where X_{Air} = concentration of element X in air,

R_{Air} = concentration of reference element in air,

X_{Crust} = concentration of element X in Earth's upper crust, and

R_{Crust} = concentration of reference element in Earth's upper crust

This method has been commonly used to distinguish elements in air arising from windblown crustal dust from those in air due to anthropogenic or natural sources (e.g., direct sublimation from crustal materials, emissions from vegetation, biogenic processes, forest wildfires, sea salt, volcanic eruptions) (CARB 1986; Gaonkar et al. 2020). The crustal metals are among the most abundant in the Earth's crust (≥ 0.1% by weight) and include aluminum, calcium, iron, magnesium, potassium, sodium, silicon, and titanium (note that magnesium and sodium were not measured in the SNAPS study) (UC Riverside 1996). Opinions range as to the value of EF that is indicative of an anthropogenic source (or some other natural source), and include EF thresholds of 2 (Kong et al. 2014; UC Berkeley 2012), 5 (CARB 1986), and 10 (Bozkurt et al. 2018; Ntziachristos et al. 2007).

For soil-derived aerosol particles, the most common choices of reference element are aluminum, silicon, and iron because their concentrations are relatively constant across particle size classes (Young et al. 2002). A number of studies examined used aluminum as the reference element: Bozkurt et al. (2018; Düzce, Turkey), Gaonkar et al. (2020; Goa, India), Arhami et al. (2009; Los Angeles, CA), UC Irvine (2010; Riverside, CA), Ntziachristos et al. (2007; Southern California freeway), and Kong et al. (2014; Dongying, China). Aluminum is considered a conservative reference element for crustal matter and usually has no contamination concern (Gaonkar et al. 2020). Aluminum and iron were therefore chosen as reference elements for the analysis; silicon was not selected because silica in large quantities (~20% by mass of slurry) was used in well stimulation on the Lost Hills Oil Field during the period of monitoring and thus the silicon level may have anthropogenic influence (CalGEM 2021).

The reference soil concentrations were the arithmetic mean elemental concentrations determined for 50 benchmark soils from throughout California (UC Riverside 1996). The soil sampling sites were mostly from agricultural fields distant from known point sources of contamination, and thus the trace element concentrations should be representative of background levels (UC Riverside 1996). This comprehensive database on 46 elements was also used in a study of resuspended, potentially lead-contaminated California soil (Young et al. 2002). The UC Riverside database did not include concentrations of bromine, chlorine, or sulfur, and thus these were not included in the enrichment factor analysis. The input elemental air concentrations were those values >RL in the dataset.

2. Results

The results of the EF analysis are shown in Figure J.3. The EFs range from 2872.3 to 0.7 with aluminum as the reference element, and from 1471.8 to 0.3 with iron as the reference element. It is evident that the mean EFs relative to aluminum are consistently higher than those relative to iron, likely reflecting a consistent discrepancy between the reference soil aluminum or iron concentrations and the concentrations in the windblown dust of Lost Hills. That is, the reference soil may overestimate the aluminum concentrations in Lost Hills' windblown dust (larger R_{Crust} values), leading to uniformly higher EF values; conversely, the reference soil may underestimate the iron concentrations in Lost Hills' windblown dust (smaller R_{Crust} values). The difference may also be the result of a mix of these factors.

The EF values for the crustal metals (denoted with a *) straddle the line representing an EF of 1, as expected, and range from 0.3 (silicon:iron)to 5.4 (calcium:aluminum). Based on this range, EF values in excess of 10 may be suggestive of an anthropogenic source. This is most compelling for selenium, antimony, and tin, whose EF values all exceed 400, with a clear demarcation between these compounds and the remaining compounds in Figure J.3.

The high EF values for selenium may relate at least in part to the fact that soils on the San Joaquin Valley's western side contain high levels of naturally occurring selenium oxyanions (Ba?uelos et al. 2005). In line with this, a number of the soil samples from the Western edge of the San Joaquin Valley in the UC Riverside database had high selenium levels compared with the rest of California (UC Riverside 1996). According to Bingham et al. (1970), "local cattlemen report that soils to the immediate south [of Western Kern County], in the Maricopa district, contain sufficient selenium to produce toxic forage" (page 200). In fact, irrigation drainage from seleniferous soils in the area led to the poisoning of wildfowl at Kesterson National Wildlife Refuge, which is approximately 140 miles North of Lost Hills (ATSDR 2003; Water Education Foundation n.d.). However, the maximum and minimum selenium concentrations in the UC Riverside Database differ by only ~14-fold so this doesn't necessarily explain the EF values for selenium of over 1000, particularly since the wind ratios and correlations suggest that selenium is not crustal.

Several of the benchmark soils in the Western San Joaquin Valley near Lost Hills had high antimony levels compared to the rest of California (UC Riverside 1996). However, the maximum and minimum values measured across the state only differ by 13-fold, not necessarily explaining the EF values of 1000, particularly since the wind ratios and correlations indicate that antimony is not crustal. A mean enrichment factor of 1,880 was determined in 29 cities, which is similar to the EFs determined in this analysis for antimony and are also indicative of anthropogenic origin (Rahn 1976).

The enrichment observed for selenium and antimony may also be related to their low DF (26% and 30%, respectively). If the few detections of selenium and antimony are replaced with their RL, the EFs are between 96 and 6890, indicating that some concentrations below the RL would be considered enriched. This may indicate that the RLs are high enough for selenium and antimony that the values above the RL are biasing the EFs upward. Although tin had a higher DF of 72%, replacement of the values above the RL with the RL led to average EFs of over 300 for both aluminum and iron as reference elements, suggesting that the RL for tin is also high enough to bias the EFs upward.

Some of the soils from the San Joaquin Valley were also high in tin as compared to the rest of California (UC Riverside 1996).

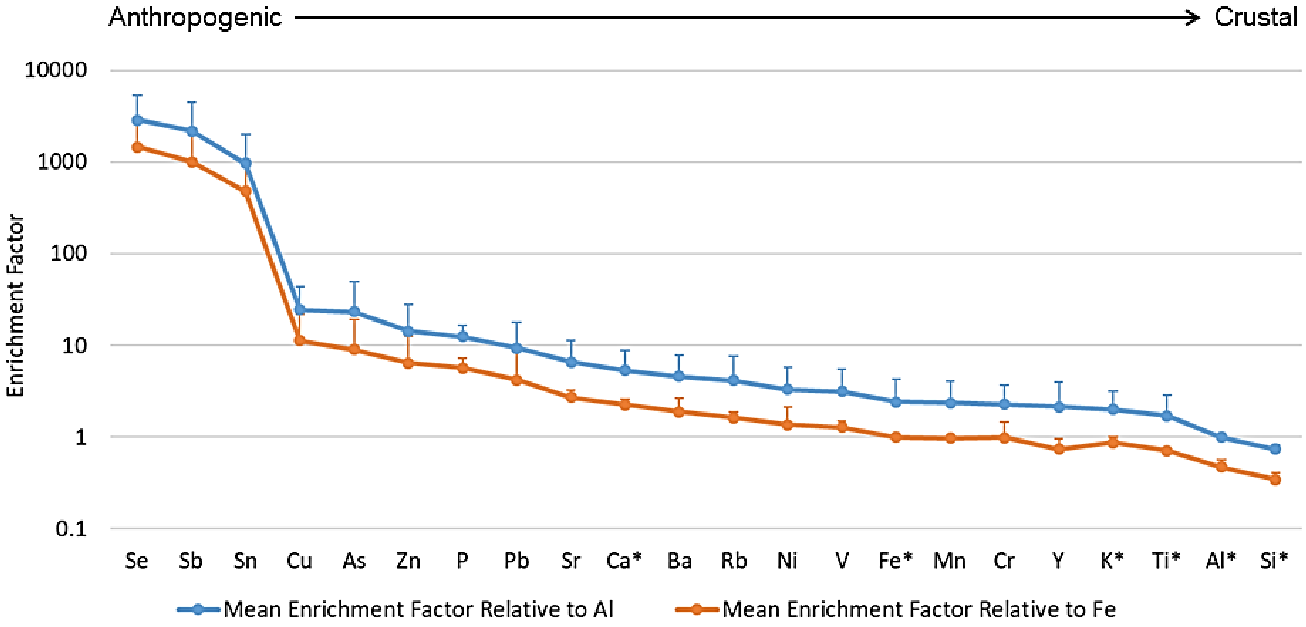


*Figure J.3 Average enrichment factors (EFs) for elements detected in Lost Hills air using aluminum (Al; blue, upper line) or iron (Fe; orange, lower line) as reference element. EFs are plotted on a logarithmic scale, meaning the EFs are plotted relative to factors of 10 (0.1, 1, 10, 100, etc.). Elements are ordered based on the EF relative to aluminum (highest to lowest). Shown as mean; error bars represent 1 standard deviation. Crustal elements are designated with a *.*

3. Discussion

Analyses of the elemental concentrations by wind speed, correlation coefficients, and EFs pointed to the following elements as likely being of crustal origin: aluminum, arsenic, barium, calcium, chromium, copper, iron, manganese, nickel, phosphorus, potassium, rubidium, silicon, strontium, sulfur, titanium, vanadium, yttrium, and zinc. This analysis supports that airborne concentrations of these elements are likely, at least in part, to be related to windblown crustal dust.

Analyses of the elemental concentrations by wind speed, correlation coefficients, and EFs pointed to the following elements as possibly being of non-crustal origin: antimony, bromine, chlorine, lead, selenium, and tin. However, these results should be treated with caution due to the influence of reporting limits on DF and the magnitude of the measured values. Of the listed compounds, antimony, selenium and tin were identified as unique by all three analyses (wind, correlation, enrichment) (note that chlorine was identified as unique in both analyses in which it was included, wind and correlation). The latter three compounds would have been enriched at their reporting limits, and thus this likely contributed to the magnitude of their enrichment factors, as did the higher natural soil abundance of these compounds in the Lost Hills area. Antimony and tin levels in Lost Hills air were much higher than those measured in various comparison sites within the San Joaquin Valley (data not shown). However, the higher reporting limits for the Lost Hills samples likely contribute to this difference. It is worth noting that while selenium was detected in 12 out of 46 samples, 8 of the detections were in consecutive samples from late November 2019 to early January 2020. This grouping of the detections during a finite period of time may also be suggestive of a unique source. Airborne particulates containing antimony, selenium, and tin can come from various sources, as described below.

Antimony: Antimony is released to the atmosphere from both natural and anthropogenic sources (ATSDR 2019). Antimony is naturally present in soil though these levels vary by location (ATSDR 2019). In the 1980s, it was estimated that 41% of antimony emissions to air were from natural sources, with a median percent contribution by wind-borne soil particles of 32.5% (ATSDR 2019). Background levels of antimony in ambient air are usually <20 ng/m^3 (ATSDR 2019). The maximum concentration measured in Lost Hills is in line with this at 20.9 ng/m^3 with a mean of 7.07 ng/m^3. According to the 2011 National Emission Inventory total national emissions, the largest contributor to atmospheric antimony is electric generation by coal, although fuel combustion in general is a major contributor; oil and gas production contributes a much smaller amount (ATSDR 2019). Brake wear is considered a major source of atmospheric antimony (Tian et al. 2014). In California Air Resource Board's (CARB) speciation profiles for total particulate matter (TPM) (CARB 2020), "Oil-fired boilers (residual)" are one of the top sources of antimony, consistent with fuel combustion as a major source.

Selenium: According to Agency for Toxic Substances and Disease Registry (ATSDR), "[c]ombustion of coal and other fossil fuels is the primary source of airborne selenium compounds" (ATSDR 2003: p. 237). In fact, selenium is at such high levels in coal fly ash that it is often used as a marker for coal-fired power plant emissions (Chow et al. 2004). The literature contains a number of articles about selenium in wastewater from coal combustion and mining and oil refining. Other sources of atmospheric selenium include incineration of rubber tires, paper, and municipal waste, selenium refining factories, base metal smelting and refining factories, mining and milling operations, and end-product manufacturers (e.g., some semiconductor manufacturers) (ATSDR 2003). In CARB's speciation profiles (CARB 2020), "EPA AVG: petroleum industry" is the fourth largest contribution to selenium levels in weight fraction of TPM.

Tin: Tin is released to the environment from both natural and anthropogenic sources (ATSDR 2005). Tin occurs naturally in the earth's crust, and thus may be released in dusts from wind storms, roads, and agricultural activities (ATSDR 2005). Anthropogenic sources of atmospheric tin include smelting and refining processes, industrial uses of tin, waste incineration, and burning of fossil fuels (ATSDR 2005). According to ATSDR (2005), "[a]mbient environmental levels of tin are generally quite low, except in the vicinity of pollution sources" (p. 252). In CARB's speciation profiles (CARB 2020), "Brake wear" is the top source for Tin.

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SNAPS Lost Hills Draft Final Report Appendices

K. Screening-Level Odor Assessment for Lost Hills

a. Introduction

Odor is one of the most common environmental air quality complaints and can affect quality of life and well-being. In a Lost Hills health survey of 27 individuals, 92.3% of respondents reported odors in their homes and community, with 11% reporting odors 2-3 times per week and 82% reporting odors every day (Earthworks and Clean Water Fund 2015). The odors were characterized as petroleum, burning oil, rotten eggs, chemicals, chlorine or bleach, sweet, sewage, and ammonia (Earthworks and Clean Water Fund 2015). Symptoms associated with the odors reported by respondents included headache, nausea/dizziness, burning or watery eyes, and nose/throat irritation (Earthworks and Clean Water Fund 2015).

Environmental odor assessment is an evolving field complicated by the subjective quality of odors, the variable sensitivity to odors, the technical difficulties associated with odor measurement, and the lack of understanding regarding the effects of complex mixtures (CASA 2015; UCLA 2019). An odorant is any substance that can elicit an olfactory response (detected by smell) (AIHA 2013). Individuals can vary greatly in their ability to detect odors, and for one individual odor sensitivity may vary by compound (AIHA 2013). Variability in odor sensitivity between individuals can relate to many factors including smoking status, age, gender, and physical/mental state (AIHA 2013).

The term *odor detection threshold* is commonly defined as the concentration at which 50% of a population would be expected to detect a compound by smell. *Odor recognition threshold* is commonly defined as the concentration at which 50% of a population would be expected to recognize the odor, meaning the odor's characteristics (e.g., fishy, rotten eggs) could be described. Both thresholds are determined based on experimental analysis involving human odor panels (CASA 2015). Continuous exposure to odorants can also result in olfactory fatigue, in which an individual loses the ability to smell the compound when it is still present.

The objectives of this screening-level odor assessment were to: (1) characterize the potential for odor detection based on air monitoring results and published odor thresholds, and (2) review the odor complaints in Lost Hills received during Study of Neighborhood Air near Petroleum Sources (SNAPS) monitoring in the context of the air monitoring data.

b. Methods

i. Odor Threshold Selection

Three sources were used to identify odor thresholds: (1) United States Environmental Protection Agency (US EPA) (1992) which summarized odor thresholds from a variety of studies; (2) the American Industrial Hygiene Association (AIHA) (2013) which summarized odor thresholds from a variety of studies; and (3) Texas Commission on Environmental Quality (TCEQ) short-term odor Effects Screening Levels (ESLs) which are developed for malodourous substances and are derived from *odor detection thresholds* or, when these are not available, *odor recognition thresholds* (TCEQ 2015a, b, 2020). The TCEQ short-term ESLs may not be odor thresholds from a specific study but are derived from this type of data (e.g., geometric mean of odor thresholds). Odor thresholds for a single compound commonly span several orders of magnitude due to individual differences and due to variabilities in testing methods including control of odorant dilution, measurement of airborne concentration at the person, and the type of testing or compound delivery (AIHA 2013; CASA 2015; US EPA 1992). In this screening level analysis, the lowest odor threshold from these sources was selected for each compound in order to ensure that potential odorant issues would be identified. In a more refined analysis, specific criteria (e.g., panel size, improved instrument calibration) could be used to evaluate threshold quality.

ii. Exposure Assumptions

The maximum measured 1-hr or 24-hr air concentration for each compound with real-time or discrete sampling data, respectively, was used to estimate exposure. For benzene, toluene, and hydrogen sulfide, for which both real-time and discrete data were available, the real-time maximum 1-hr average was used. As discussed in Appendix J, Section b, the maximum 24-hr averages may underestimate the maximum 1-hr averages.

iii. Odor Quotient Calculations

Odor quotients (OQs) were calculated by dividing the maximum air concentration by the selected odor threshold. OQs that exceed one indicate that the substances could be detected by residents of Lost Hills at the maximum concentration measured. OQs that do not exceed one indicate that the substances are less likely to be detected by residents of Lost Hills at the maximum concentration.

$$Odor\ Quotient = \frac{Maximum\ Air\ Concentration\ (\frac{\mu g}{m^3})}{Odor\ Threshold\ (\frac{\mu g}{m^3})}$$

c. Results and Discussion

i. Odor Thresholds and Odor Quotients

Summary 1K: Sixty-five of the detected compounds had published odor threshold(s). For eight compounds, the maximum air concentration exceeded the selected (lowest) odor threshold indicating that the compounds may be detected by smell. Hydrogen sulfide and ozone exceeded the selected odor thresholds most frequently.

Office of Environmental Health Hazard Assessment (OEHHA) identified odor thresholds for sixty-five of the compounds detected in SNAPS air monitoring (Table K.3) (AIHA 2013; TCEQ 2015a, b, 2020; US EPA 1992). Chlorine was excluded as the odor thresholds are for chlorine gas and SNAPS measured chlorine as part of total suspended particulate. Eight chemicals – including four sulfide (sulfur-containing) compounds, which are well-known for being odorous at low concentrations - had maximum air concentrations that exceed the selected odor threshold (OQ>1), including acetaldehyde, dimethyl disulfide, ethyl methyl sulfide, hydrogen sulfide, isobutyl mercaptan, m-diethylbenzene, p-diethylbenzene, and ozone (Table K.3; Figure K.1). This suggests that these compounds may at times be detected by smell in Lost Hills. The odor characteristics of these compounds are described in Table K.1. Compounds that were not detected above the odor threshold are less likely to be perceived by residents of Lost Hills. However, detection cannot be ruled out because: (1) odor thresholds typically represent a detection/recognition level for 50% of the population, so some individuals may detect the odor at lower concentrations, and (2) due to the sampling methodology some peaks may be higher than reflected in the SNAPS data.

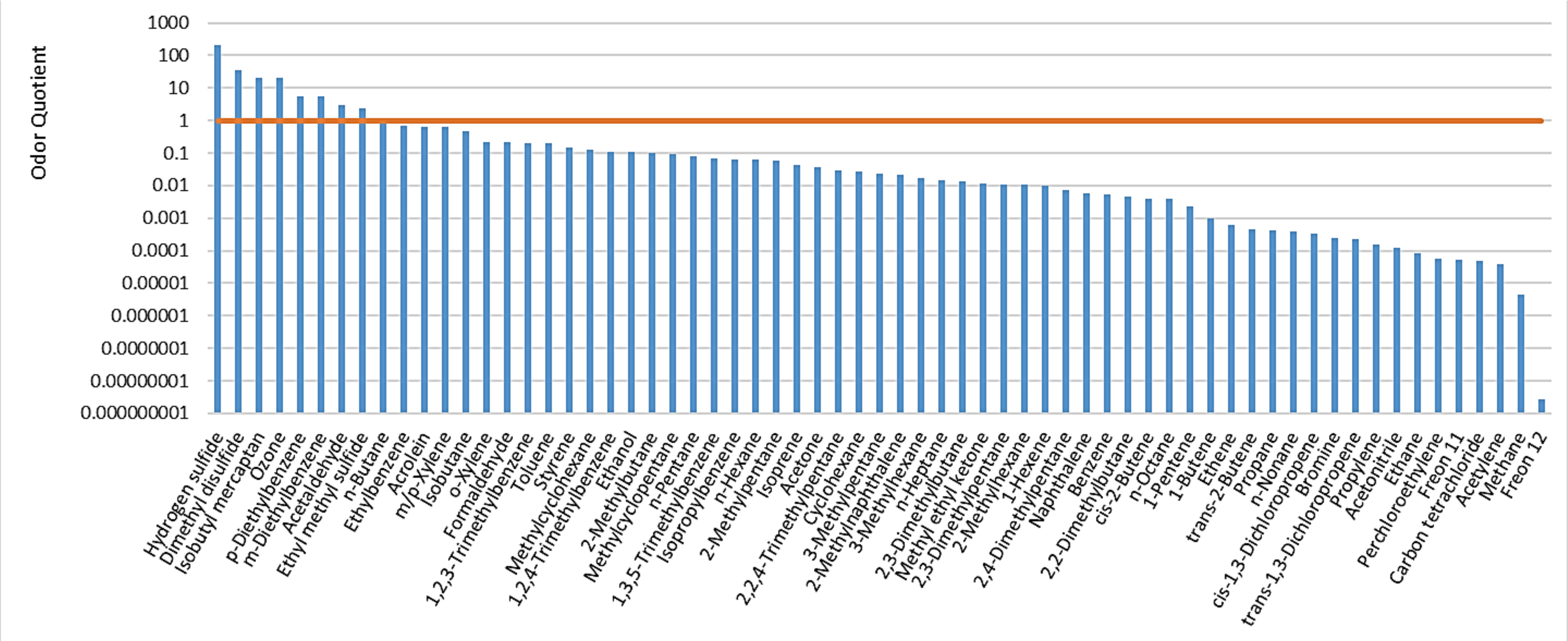

Figure K.1 Odor quotients (OQs) for the 65 compounds with available odor threshold(s). The orange horizontal line denotes an OQ of 1, below which the compound is less likely to be detected by smell.

Table K.1 Odor description for compounds with an odor quotient (OQ)>1. Odor descriptions were compiled from AIHA (2013) and TCEQ (2015b).

Compound	**CAS Registry Number**	**Odor Description**	**Range of Reported Odor Thresholds ($\mu g/m^3$)[a]**
Acetaldehyde	75-07-0	pleasant, fruity at low concentration; pungent at high concentration	2.7 - 1,800,000
m-Diethylbenzene[b]	141-93-5	-	2.1 - 390
p-Diethylbenzene[b]	105-05-5	-	2.1 - 390
Dimethyl disulfide	624-92-0	rotten egg, garlic, vegetables, putrid, asparagus	1.1 – 5,600
Ethyl methyl sulfide	624-89-5	sulfurous	22
Hydrogen sulfide	7783-06-4	rotten egg	0.056 – 5,000
Isobutyl mercaptan	513-44-0	pungent	3.6
Ozone	10028-15-6	pungent, thunder storm	6.4 - 500

Abbreviations: CAS, Chemical Abstracts Service

[a] Range of reported odor thresholds from AIHA, TCEQ, and US EPA (AIHA 2013; TCEQ 2015a, b, 2020; US EPA 1992).

[b] Odor threshold is for diethylbenzene, mixed isomers

Ethyl methyl sulfide and isobutyl mercaptan were each detected in one of 23 samples (4%). Dimethyl disulfide was also detected in one of 23 samples (4%); however, the reporting limit (9.63 $\mu g/m^3$) is greater than the selected odor threshold (1.1 $\mu g/m^3$) so it is unknown how frequently this compound exceeded the odor threshold. The diethylbenzenes both exceeded the selected odor threshold in 0.09% of samples and acetaldehyde exceeded the selected odor threshold in 23% of samples. Hydrogen sulfide and ozone exceeded the selected (lowest) odor thresholds most frequently at 87% and 99% of samples, respectively.

Hydrogen sulfide occurs naturally in crude petroleum and natural gas and its odor has been associated with oil and gas production (McCallum et al. 2016). Crude oil with high sulfur content (>1%) is referred to as "sour" and oil with low sulfur content (<0.5%) is referred to as "sweet" (CEC 2006). Lost Hills Oil Field is considered a sour oil field with a ~1% sulfur content indicating that substantial quantities of hydrogen sulfide may be present in the oil (CEC 2006; US EPA 1993).

There are a wide range of reported odor thresholds for hydrogen sulfide (0.056 – 2,000 μg/m^3) illustrating that the ability to smell hydrogen sulfide may be highly variable in the human population and/or that the studies may vary in quality (AIHA 2013). Other agencies have reported the average *odor detection threshold* as 0.03 to 0.05 ppm (42- 70 μg/m^3) (CARB n.d.-a) or 0.5-1 ppb (0.70 - 1.4 μg/m^3) (ATSDR 2001). The California Ambient Air Quality Standard (CAAQS) for hydrogen sulfide was developed, in part, for the purpose of odor control at 0.03 ppm (42 μg/m^3) for a 1-hr average (OEHHA 2008). However, at the current CAAQS, hydrogen sulfide would be detectable by 83% of the population and would be discomforting to 40% of the population (OEHHA 2008 Appendix D2; Amoore and Hautala 1983). Importantly, none of the hydrogen sulfide 1-hr samples exceeded this value; the maximum concentration was only 27% of the standard. According to the World Health Organization (WHO), hydrogen sulfide concentrations should not exceed 7 μg/m^3 (30-minute averaging time) to avoid odor nuisance (WHO 1981); this concentration was exceeded in only one sample out of 7,204 in Lost Hills (0.014%; 1-hr time period). This screening-level assessment demonstrates that there is the potential for residents to detect hydrogen sulfide as it frequently exceeds the selected (lowest) odor threshold; however, it does not exceed other values suggested for odor control.

For ozone and acetaldehyde, a portion of their ambient air concentrations is likely formed through secondary chemical reactions in the air. There is a wide range of reported odor thresholds for ozone (6.4 – 500 μg/m^3) and acetaldehyde (2.7-1,800,000 μg/m^3) illustrating that the ability to smell them may be highly variable in the human population and/or that the studies vary in quality (AIHA 2013). Ozone did not exceed the National or California Ambient Air Quality Standards, which were set for health protection, but it is acknowledged that some people can smell ozone at lower levels (CARB n.d.-b). Acetaldehyde did not exceed the WHO-reported odor threshold of 90 μg/m^3 (WHO 1994). The 2018 statewide mean acetaldehyde concentration is 1.73 μg/m^3 (CARB 2021), which also exceeds the selected odor threshold but not the WHO odor threshold. This screening-level assessment demonstrates that there is the potential for residents to detect ozone and acetaldehyde, as the compounds frequently exceed the selected (lowest) odor thresholds; however, a more refined analysis is needed to determine the best odor thresholds and to compare Lost Hills to other locations.

ii. Relationship to Odor Complaints

Summary 2K: There were several odor complaints from community members during the sampling period. Ozone concentrations were high around the time of several of the odor complaints, however, it is difficult to identify the exact cause of the odors.

California Air Resource Board (CARB) received odor complaints on four days during the monitoring period and one day after monitoring ended (Table K.2). In addition, a community group commented that several residents in June and July 2019 smelled a strong oil/gas odor near the western edge of King Street from roughly 5:00-7:00 AM.

Table K.2 Odor complaints received during and after SNAPS air monitoring. Some complaints included reports of health symptoms and wind direction.

Date	Time	Location	Description (odor characteristic; health symptom; wind direction)
2/24/2020	6:00 PM through the evening	Fresno St. and Lost Hills Rd.	Strong oil/gas smell; headaches, throat irritation, and difficulty breathing; west north westerly wind
2/24/2020	6:00 PM - 6:54 PM	Bayer St.	Strong smell; throat hurts; wind direction is from west to east
2/24/2020	7:00 PM	Bayer St.	Oil or burned rubber smell; eyes and throat hurt
2/24/2020	7:00 PM	Bayer St.	Strong burned rubber smell; wind from south to west
3/4/2020	5:18 PM	Bayer St.	Strong rotting blood/meat smell; wind from south to west
4/15/2020	12:20 PM - 1:00 PM	North Lost Hills near Wonderful Park	Strong oil and gas smell
4/15/2020	1:00 PM	Wonderful Park	Strong oil/welding smell
4/18/2020	6:10 PM - 6:15 PM and	Bayer St.	Strong medicine smell

	6:10 PM - 6:35 PM[a]		
5/2/2020[b]	3:00 PM - 6:08 PM	Lost Hills	Sewage smell; coming from north
5/2/2020[b]	5:57 PM and 5:45 PM - 6:10 PM[c]	Bayer St.	Strong rotten mud smell; wind from the northwest or north

[a]Two calls from the same person in order to clarify a misspoken date
[b]After SNAPS air monitoring was completed
[c]Two calls from the same person to provide more information

Only one complaint date overlapped with volatile organic compounds collection (3/4/2020). On this day, dimethyl disulfide, ethyl methyl sulfide, and isobutyl mercaptan were below the reporting limit. The reporting limit for dimethyl disulfide is higher than the selected odor threshold precluding an evaluation of the likelihood of detection by smell. Acetaldehyde was detected at 1.623 $\mu g/m^3$, less than the selected odor threshold value of 2.7 $\mu g/m^3$.

For real-time samples, concentrations of hydrogen sulfide, ozone, m-diethylbenzene and p-diethylbenzene were examined at the date/start time of the odor complaints. m- and p-Diethylbenzene were not measured or were not measured over the selected odor threshold value at any of the complaint start times. The air concentrations of hydrogen sulfide and ozone exceeded the selected (lowest) odor threshold values at the complaint times. However, the measured air concentrations for hydrogen sulfide at the start time of the odor complaints were all between the 25th and 75th percentile, indicating they are typical. For ozone, two of the measured air concentrations were between the 25th and 75th percentile and two exceeded the 75th percentile indicating they are higher than typical. Most results in the two hours before each odor complaint were similar: the diethylbenzenes were not measured or did not exceed the selected odor threshold, hydrogen sulfide exceeded the selected odor threshold but concentrations were not atypical (less than 75th percentile). In the two hours before the odor complaint, ozone exceeded the selected odor threshold and concentrations were higher than the 75th percentile on three dates (2/24/2020, 3/4/2020, and 4/15/2020).

Hydrogen sulfide concentrations exceeded the selected odor threshold at the time of the odor complaints but the odor complaints do not align with atypical concentrations. Ozone was detected at high concentrations around the time of the odor complaints suggesting it could be contributing to strong odors. It is difficult to determine the exact cause of an odor with the SNAPS air monitoring data because: (1) the odors may be related to chemicals that were not measured or detected, (2) the concentrations measured at the monitoring site may be different than at other locations in Lost Hills, and (3) a lack of resolution for odorants that did not have continuous air monitoring. In addition, the filing of specific complaints is unlikely to reflect frequency and magnitude of odor issues (Earthworks and Clean Water Fund 2015).

d. Conclusions and Limitations

The complexity and variability of the olfactory system makes it difficult to assign odors to a specific compound and concentration. Thus, the calculation of odor quotients based on maximum concentrations can be viewed as a screen for potential odor impacts in Lost Hills. One limitation of this assessment is that environmental odors are commonly mixtures and the interplay of odorants can be complex with synergistic and antagonistic effects (UCLA 2019). It is possible in environmental samples for one odor to mask another. However, for this screening-level assessment each compound was assessed independently. Further, the odor thresholds were selected by choosing the lowest value and were not assessed for quality. A more refined assessment should include criteria for odor threshold selection.

The potential for indirect health effects from odor exposure is plausible but was not quantitatively assessed. Common symptoms arising from odor exposure include headaches, nasal congestion, eye, nose, and throat irritation, hoarseness, sore throat, cough, chest tightness, and shortness of breath, among others (ATSDR 2015). Similar health outcomes were reported in the odor complaints and the community health survey in Lost Hills (Table K.2, Earthworks and Clean Water Fund 2015). The ability of these compounds to cause irritation is addressed in the development of HGVs and covered by the health risk assessment, but indirect symptoms from odor are not addressed.

This screening-level assessment indicates that most of the detected chemicals are unlikely to be perceived by smell at the maximum concentrations measured, albeit their concentrations could be higher in other locations or at times when they were not measured. It is also possible that peak concentrations were missed as a result of the 24-hr sampling duration for some compounds. The compounds that exceeded their odor threshold were mainly aldehydes and sulfur-containing compounds, which are known to have low odor thresholds and unpleasant odors that can affect quality of life and well-being. In conclusion, this analysis suggests that compounds in the ambient air could be perceived by smell by the residents in Lost Hills.

*Table K.3 Selected (lowest) odor thresholds, maximum air concentrations, and odor quotients. Odor quotients that exceed one are in **bold**.*

Compound	CAS Registry Number	Selected Odor Threshold ($\mu g/m^3$)	Source	Max Air Conc. ($\mu g/m^3$)	Sampling Duration (hr)	Odor Quotient
Acetaldehyde	75-07-0	2.7	AIHA/US EPA[b]	8.024	24	**3.0**
Acetone	67-64-1	940	AIHA[a]	35.61	24	0.038

Compound	CAS Registry Number	Selected Odor Threshold (µg/m^3)	Source	Max Air Conc. (µg/m^3)	Samp-ling Duration (hr)	Odor Quotient
Acetonitrile	75-05-8	22,000	AIHA[b]	2.685	24	0.00012
Acetylene	74-86-2	240,000	AIHA[b]	9.26	1	0.000039
Acrolein	107-02-8	8.3	AIHA[b]	5.5	24	0.66
Benzene	71-43-2	1,500	AIHA[b]	8.04	1	0.0054
Bromine	7726-95-6	<65	AIHA[b]	0.0159	24	0.00024
n-Butane	106-97-8	1,000	AIHA[a]	784	1	0.78
1-Butene	106-98-9	830	AIHA[b]	0.807	1	0.00097
cis-2-Butene	590-18-1	830	AIHA[b]	3.16	1	0.0038
trans-2-Butene	624-64-6	830	AIHA[b]	0.391	1	0.00047
Carbon tetrachloride	56-23-5	10,580	AIHA[a]	0.516	24	0.000049
Cyclohexane	110-82-7	1,800	AIHA[a]	48.6	1	0.027
cis-1,3-Dichloropropene	542-75-6	<4,500	AIHA[a]	1.542	24	0.00034
trans-1,3-Dichloropropene	542-75-6	<4,500	AIHA[a]	0.998	24	0.00022
m-Diethylbenzene	141-93-5	2.1	AIHA[b]	11.3	1	**5.4**
p-Diethylbenzene	105-05-5	2.1	AIHA[b]	11.8	1	**5.6**

Compound	CAS Registry Number	Selected Odor Threshold (µg/m^3)	Source	Max Air Conc. (µg/m^3)	Sampling Duration (hr)	Odor Quotient
2,2-Dimethylbutane	75-83-2	1,500	AIHA[b]	6.86	1	0.0046
2,3-Dimethylbutane	79-29-8	1,500	AIHA[b]	19.8	1	0.013
Dimethyl Disulfide	624-92-0	1.1	AIHA[b]	38.12	24	**35**
2,3-Dimethylpentane	565-59-3	1,700	AIHA[b]	17.9	1	0.011
2,4-Dimethylpentane	108-08-7	1,700	AIHA[b]	12.6	1	0.0074
Ethane	74-84-0	25,000,000	AIHA[a]	2,030	1	0.000081
Ethanol	64-17-5	170	AIHA[b]	18.64	24	0.11
Ethene	74-85-1	20,000	AIHA[a]	12.1	1	0.00061
Ethyl methyl sulfide	624-89-5	22	TCEQ[c]	52.92	24	**2.4**
Ethylbenzene	100-41-4	<10	AIHA[a]	7.05	1	0.71
Formaldehyde	50-00-0	33	AIHA[d]	6.95	24	0.21
Freon 11	75-69-4	28,000	AIHA[b]	1.46	24	0.000052
Freon 12	75-71-8	988,000,000	AIHA[a]	2.619	24	0.0000000027
n-Heptane	142-82-5	1,700	AIHA[b]	26.3	1	0.015

Compound	CAS Registry Number	Selected Odor Threshold (μg/m^3)	Source	Max Air Conc. (μg/m^3)	Sampling Duration (hr)	Odor Quotient
n-Hexane	110-54-3	1,500	AIHA[b]	91.2	1	0.061
1-Hexene	592-41-6	480	AIHA[b]	4.83	1	0.010
Hydrogen sulfide	7783-06-4	0.056	AIHA[a]	11.33	1	**200**
Isobutane	75-28-5	1,000	AIHA[a]	477	1	0.48
Isobutyl mercaptan	513-44-0	3.6	TCEQ[c]	73.73	24	**20**
Isoprene	78-79-5	130	TCEQ[c]	5.46	1	0.042
Isopropylbenzene	98-82-8	25	US EPA[a]	1.56	1	0.062
Methane	74-82-8	1,900,000,000	AIHA[a]	8,270	1	0.0000044
Methylcyclohexane	108-87-2	600	AIHA[b]	78.1	1	0.13
Methylcyclopentane	96-37-7	1,500	AIHA[b]	143	1	0.095
2-Methylbutane	78-78-4	3,800	AIHA[b]	371	1	0.098
Methyl ethyl ketone	78-93-3	210	AIHA[b]	2.515	24	0.012
2-Methylhexane	591-76-4	1,700	AIHA[b]	18.1	1	0.011
3-Methylhexane	589-34-4	1,700	AIHA[b]	28.2	1	0.017
2-Methylnaphthalene	91-57-6	4	AIHA[b]	0.085	24	0.021

Compound	CAS Registry Number	Selected Odor Threshold (µg/m^3)	Source	Max Air Conc. (µg/m^3)	Samp-ling Duration (hr)	Odor Quotient
2-Methylpentane	107-83-5	1,500	AIHA[b]	89.3	1	0.060
3-Methylpentane	96-14-0	1,500	AIHA[b]	34.1	1	0.023
Naphthalene	91-20-3	7	AIHA[b]	0.039	24	0.0056
n-Nonane	111-84-2	12,000	AIHA[b]	4.51	1	0.00038
n-Octane	111-65-9	3,100	AIHA[b]	11.7	1	0.0038
Ozone	10028-15-6	6.4	AIHA[b]	130.55	1	**20**
n-Pentane	109-66-0	3,800	AIHA[b]	302	1	0.079
1-Pentene	109-67-1	290	TCEQ[c]	0.663	1	0.0023
Perchloroethylene	127-18-4	5,200	AIHA[b]	0.285	24	0.000055
Propane	74-98-6	2,700,000	AIHA[a]	1,170	1	0.00043
Propylene	115-07-1	17,300	AIHA[a]	2.65	1	0.00015
Styrene	100-42-5	12	AIHA[a]	1.76	1	0.15
Toluene	108-88-3	80	AIHA/US EPA[b]	16.2	1	0.20
1,2,3-Trimethylbenzene	526-73-8	30	AIHA[a]	5.96	1	0.20
1,2,4-Trimethylbenzene	95-63-6	30	AIHA[a]	3.15	1	0.11

Compound	CAS Registry Number	Selected Odor Threshold (µg/m^3)	Source	Max Air Conc. (µg/m^3)	Samp-ling Duration (hr)	Odor Quotient
1,3,5-Trimethylbenzene	108-67-8	30	AIHA[a]	2.01	1	0.067
2,2,4-Trimethylpentane	540-84-1	3,100	AIHA[b]	93.9	1	0.030
m/p-Xylene	1330-20-7	52	AIHA[b]	33.2	1	0.64
o-Xylene	95-47-6	52	AIHA[b]	11.4	1	0.22

Abbreviations: CAS, Chemical Abstracts Service; conc., concentration; max, maximum

[a] Type of odor threshold (detection/recognition) not reported
[b] *Odor detection threshold*
[c] TCEQ value derived from odor thresholds
[d] *Odor recognition threshold*
Sources include: AIHA 2013; TCEQ 2020; US EPA 1992.

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