Ensuring Safe and Reliable Underground Natural Gas Storage: Public Health and Environment Subgroup Report

Appendix to the Final Report of the Interagency Task Force on Natural Gas Storage Safety

December 2016

Federal Interagency Task Force on Natural Gas Storage Safety: Public Health and Environment Subgroup Report

Executive Summary

On October 23, 2015, the largest methane leak from a natural gas storage facility in United States history was discovered by the Southern California Gas Company (SoCalGas) at a well within its Aliso Canyon Underground Storage Field in Los Angeles County. On November 19, 2015, the Los Angeles Department of Public Health (LADPH) issued a Public Health Directive ordering SoCalGas to provide temporary relocation assistance to residents impacted by the natural gas leak at its Standard Sesnon-25 well site (SS-25). After numerous attempts to stop the leak, on February 11, 2016, SoCalGas reported that the leak had been temporarily sealed. On February 18, 2016, California state regulators confirmed that the leaking well had been permanently sealed. A full timeline of events can be found in Table ES-1.

Motivated by the events at Aliso Canyon, on April 1, 2016, the Obama Administration formed an Interagency Task Force on Natural Gas Storage Safety to better understand the overall safety and environmental impacts of our nation's natural gas storage infrastructure. Congress codified the Task Force through the Securing America's Future Energy: Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 (PIPES Act). The Department of Energy (DOE) and Department of Transportation (DOT) co-chaired the Task Force. Congress directed the Task Force to review the Aliso Canyon events and make recommendations to reduce the probability, and minimize the impacts, of any future occurrence of similar incidents at any of the approximately 400 natural gas storage facilities across the country. The Task Force convened three separate working groups to evaluate three aspects of the natural gas leak and response: (1) the physical integrity of natural gas storage facilities, (2) the reliability of natural gas supplies, and (3) the public health and environmental impacts associated with the leak. On October 18, 2016, the Task Force issued its final report, "Ensuring Safe and Reliable Underground Natural Gas Storage," which summarizes the findings and recommendations made by each of the three working groups.[1]

This report addresses the public health and environmental impacts associated with the leak at Aliso Canyon; the physical integrity of the storage facilities and the reliability of natural gas supplies are addressed in separate reports. It was prepared by the Public Health and Environment Subgroup established under the Task Force, whose members include the Environmental Protection Agency, the Centers for Disease Control and Prevention, the Department of Transportation/Pipeline Hazardous Materials Safety Administration, and the National Oceanic and Atmospheric Administration. The scope of the report includes summarizing the actions taken by local, state and federal agencies to monitor and mitigate impacts to public health and the environment, reporting the best estimates of those impacts, and recommending actions for local, state and federal agencies to take in order to be prepared in the event that a release from a natural gas storage facility should occur in the future.

[1] http://energy.gov/downloads/report-ensuring-safe-and-reliable-underground-natural-gas-storage

State and local agencies began monitoring air quality near the leaking well and the nearby Porter Ranch community within three days of discovery of the release. Within two weeks, state and local agencies issued orders to SoCalGas to take actions to stop the leak, monitor the release, and reduce impacts to the community. SoCalGas activated the Incident Command System (ICS), as outlined in the National Incident Management System, to organize its response to the incident. California and the Los Angeles metropolitan area have extensive experience with ICS principles. As a result, the response was well-coordinated among federal, state and local authorities and SoCalGas. However, earlier deployment of a Unified Command in the ICS structure, and the presence of an expert advisory group, would have supported decision making and improved public health messaging and community outreach.

Air quality monitoring carried out by the South Coast Air Quality Management District (SCAQMD) and the California Air Resources Board (CARB), supplemented by monitoring conducted by the Los Angeles Unified School District (LAUSD), SoCalGas, and the University of California, Los Angeles (UCLA), provided the public and responding agencies with near-real-time information about pollutants of concern.[2] The report contains detailed information about monitoring strategies and techniques, and summarizes state and local agency statements about health risk based on collected air monitoring data. The report recommends that areas with natural gas storage facilities have the capacity to establish similarly robust air quality monitoring in order to adequately characterize the public health impacts of releases. Under a legal order issued by the SCAQMD Hearing Board, research funded by SoCalGas will investigate whether there could be long-term health effects from human exposures to pollutants emitted during the leak, including natural gas odorants.

Methane, the primary component of the natural gas released during the leak, is a powerful greenhouse gas. To assess the magnitude of the release, state and local agencies needed to measure and quantify the amount of methane emissions released. Measurements were taken by airplanes and satellites, near the ground around the well site, and at tall monitoring network towers. The inventory of natural gas in the reservoir before and after the release was also analyzed to estimate emissions. A number of studies estimated the magnitude of methane released from the leak with varying results, as discussed in this report. CARB assessed data from these studies and conducted its own analysis of additional data. On October 21, 2016, CARB released an estimate of the leak of approximately 100,000 metric tons of methane. If a similar leak were to occur elsewhere, it is unclear whether comparable quantification capabilities would be available, because other natural gas storage facilities may not be covered by existing monitoring networks and may not have access to multiple, rapidly deployable measurement technologies.

After the leak was permanently sealed, many residents who had relocated from the Porter Ranch community during the leak began to return home from temporary housing. From late February to March 2016, LADPH received a large number of health complaints, similar to those received during the gas leak, from the Porter Ranch community. These included symptoms such as headaches, nasal congestion, sore throat, respiratory complaints, nausea and dizziness. In

[2] We note that monitoring can serve different purposes. This report addresses monitoring that was conducted to assess human exposure to chemicals emitted by the leak as well as the environmental impacts associated with escaping GHG emissions. The report covering the physical integrity of natural gas storage facilities addresses monitoring for the prevention, detection, and repair of leaks at natural gas storage facilities.

response to these complaints, LADPH conducted an assessment of the indoor environment in Porter Ranch homes as well as a Community Assessment for Public Health Emergency Response (CASPER) health assessment. The results of these studies, which found elevated levels of specific metals, led LADPH to direct SoCalGas to pay for professional home cleaning. Subsequently, the Los Angeles County Superior Court ordered SoCalGas to clean nearly 1,500 homes of residents who were relocated. According to SoCalGas, all residents who were relocated have returned home after the completion of exterior and interior home cleanings. LADPH had the resources to undertake post well closure analyses to identify potential contaminants in the homes and to conduct a community health assessment. Many of LADPH's actions provide a useful template for other agencies to consider if faced with similar situations.

Although not required by federal or state regulations, on December 18, 2015, SoCalGas committed to "mitigate environmental impacts from the actual natural gas released from the leak" and "work with state officials to develop a framework that will help us achieve this goal." On January 6, 2016, California Governor Jerry Brown ordered that CARB, "in consultation with appropriate state agencies, shall develop a program to fully mitigate the leak's emissions of methane" and directed that, "the mitigation program shall be funded by the Southern California Gas Company." The lack of standards to guide voluntary mitigation of methane coupled with ongoing litigation create uncertainty regarding the final outcome of mitigation. Furthermore, if a similar leak were to occur elsewhere, there is no mechanism to ensure comparable mitigation would take place.

The response to the Aliso Canyon natural gas leak was complex and without precedent. Table ES-2 provides recommendations drawn from the Public Health and Environment Subgroup's analysis of actions taken by federal, state and local agencies to protect public health, from the time the release was discovered until residents reoccupied their homes several months after the leaking well was closed. The recommendations include a number of actions taken by state and local agencies that could be considered "best practices." State and local agencies, and facility owners and operators, are encouraged to review these practices as they prepare for the possibility of a similar incident in the future.

Table ES-1: Timeline of Events Associated with the Aliso Canyon Natural Gas Leak

Oct 23, 2015	Natural gas leak from well SS-25 was discovered by Southern California Gas (SoCalGas)
Oct 24, 2015	South Coast Air Quality Management District (SCAQMD) received the first air quality complaints resulting from odors associated with the natural gas leak.
Oct 26, 2015	SCAQMD began air sampling and monitoring activities in the local community.
Oct 30, 2015	SoCalGas began air sampling.
Oct 31, 2015	LA County Fire Department Health Hazardous Materials Divison (LA County Fire/HazMat) received a spill report from the California Office of Emergency Services (Cal/OES) and sent a team to investigate.
Late Oct – Dec 22, 2015	SoCalGas attempted seven separate "top kill" operations to seal well SS-25.
Nov 5, 2015	SCAQMD issued a "Notice to Comply" directing SoCalGas to abate the mercaptan odors from the natural gas leak.
Nov 7, 2015	California Energy Commission sponsored first airborne methane sampling collection. Flights continued through February, 2016.
Nov 10, 2015	SoCalGas provided a response to the "Notice to Comply" stating that its investigation and response to the leak incident was ongoing.

Nov 10, 2015	National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL) conducted on-site field survey of the Aliso Canyon facility.
Nov 13, 2015	NASA/JPL began satellite imaging of methane plumes.
Nov 18, 2015	California Natural Resources Agency/Department of Conservation/Division of Oil, Gas and Geothermal Resources (DOGGR) issued order requesting SoCalGas to provide information on well SS-25.
Nov 19, 2015	Los Angeles Department of Public Health (LADPH) issued Public Health Directive ordering SoCalGas to continue abatement, eliminate odorous emissions, and provide relocation assistance.
Nov 23, 2015	SCAQMD issued Notice of Violation to SoCalGas for creating a public nuisance.
Nov 25, 2015	SoCalGas began drilling a relief well to conduct a "bottom kill" operation.
Nov 30, 2015	Los Angeles Unified School District (LAUSD) began air sampling.
Dec, 2015	SCAQMD and California Air Resources Board (CARB) deployed fixed site ambient air monitoring.
Dec, 2015 – Feb, 2016	California Public Utilities Commission (CPUC) issued a series of directives to SoCalGas for information related to the leak and operations at the Aliso Canyon field.
Dec 7, 2015	City of Los Angeles filed a civil lawsuit against SoCalGas seeking relief related to the leak's climate impacts.
Dec 10, 2015	DOGGR issued order requiring SoCalGas to develop plans to capture escaping gas, stop the leak and communicate with state and local regulators.
Dec 16, 2015	EPA Federal On-Scene Coordinators (FOSCs) visited Aliso Canyon facility (with LA County Fire/HazMat).
Dec 18, 2015	EPA issued an information request to SoCalGas under Clean Air Act (CAA) Section 114 authority.
Dec 18, 2015	Governor Brown's office issued a letter to SoCalGas and directed states agencies to investigate the well leak and public health concerns.
Dec 18, 2015	SoCalGas sent a letter to Governor Brown confirming company's commitment to mitigate environmental impacts related to the leak.
Dec 21, 2015	SoCalGas contracted with Aerodyne to begin a tracer study to gauge methane concentrations downwind of the leak.
Dec 22, 2015	CARB installed first real-time community monitoring stations (sites 1 and 2).
Dec 24, 2015	CARB initiated a real-time data access portal on its website.
Jan, 2015	CARB and SCAQMD collaborated to expand the number of real-time community monitoring stations (sites 3-8).
Jan 3, 2016	SoCalGas began mitigation efforts to knock down mist escaping from well SS-25.
Jan 4, 2016	SoCalGas submitted a permit application to SCAQMD to construct and operate temporary equipment to capture and control natural gas from the leak.
Jan 6, 2016	Governor Brown's office issued Emergency Proclamation to ensure thorough state response to the leak.
Jan 7, 2016	EPA activated its Regional Response Team 9 (RRT9) under National Oil and Hazardous Substances Pollution Contingency Plan authority (NCP, authorized by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA)).
Jan 8, 2016	CalEPA's Office of Environmental Health Hazard Assessment (OEHHA) issued first health risk assessment, based on a review of collected air sampling data.
Jan 13 – Jan 28, 2016	Dr. Michael Jerrett (University of California, Los Angeles, Fielding School of Public Health (UCLA FSPH)) collected air sampling data.
Jan 15, 2016	Public meeting was convened by State leadership, attended by EPA.
Jan 15, 2016	OEHHA convened panel of scientific and medical experts to review public health concerns.
Jan 22, 2016	SoCalGas entered into a Unified Command with the LA County Fire/HazMat and LADPH.
Jan 26, 2016	SCAQMD filed a civil penalty lawsuit against SoCalGas in LA Superior Court for creating a public nuisance.

Feb, 2016	SoCalGas conducted a stored gas inventory analysis to estimate the methane emissions released by the leak.
Feb 2, 2016	LA County District Attorney filed a criminal lawsuit against SoCalGas.
Feb 11, 2016	SoCalGas reported that the leak had been temporarily sealed.
Feb 12, 2016	OEHHA's expert panel issued report on public health risks related to the leak.
Feb 13, 2016	CARB released first preliminary estimate of total methane emissions based on recorded flight data.
Feb 16, 2016	CARB and SCAQMD issued "Criteria for Determining when Air Quality in the Porter Ranch and Surrounding Communities Has Returned to Typical (pre-SS-25 Leak) Levels."
Feb 18, 2016	DOGGR issued a determination that the well leak was permanently sealed.
Feb 19, 2016	The Unified Command for the Aliso Canyon incident stood down; the CPUC began its lead role in the investigation phase of the incident.
Late Feb, 2016	Residents began returning to their homes from temporary housing.
Late Feb, 2016	LADPH began receiving a new influx of health complaints from the Porter Ranch community.
Late Feb, 2016	Dr. Michael Jerrett (UCLA FSPH) conducted indoor air and particulate sampling in seven impacted homes.
Mar 8, 2016	LADPH issued a Public Health Directive to SoCalGas to clean oily residue from surfaces in the Porter Ranch community.
Mar 10, 2016	LADPH began Community Assessment for Public Health Emergency Response (CASPER).
Mar 14, 2016	SoCalGas began indoor air sampling (results released March 17, 2016).
Mar 14, 2016	CARB released draft greenhouse gas (GHG) mitigation program recommendations for public comment.
Mar 23, 2016	LADPH announced a protocol for sampling home interiors for residual contamination from the leak (surface wipe sampling and indoor air sampling).
Mar 24, 2016	SoCalGas submitted comments on CARB draft GHG mitigation program.
Mar 31, 2016	CARB recommended a GHG mitigation program to address the leak's climate impacts.
Apr 20, 2016	LADPH collected soil samples from six sites near the leak.
May 11, 2016	OEHHA issued latest health risk statement.
May 13, 2016	LADPH released a public health assessment report, "Environmental Conditions and Health Concerns in Proximity to Aliso Canyon Following Permanent Closure of Well SS-25."
May 13, 2016	LADPH issued a directive to SoCalGas to offer comprehensive cleaning to homes in Porter Ranch.
May 20, 2016	Los Angeles Superior Court issued a ruling directing SoCalGas to pay for the cleaning of homes that participated in the relocation program.
May 25, 2016	LADPH directed SoCalGas to implement its Interior Home Cleaning Work Plan.
June 17, 2016	SoCalGas completed its indoor cleaning program,
Late June, 2016	SoCalGas ended the temporary relocation program.
Sep 13, 2016	SoCalGas agreed to pay $4 million to settle criminal charges filed by the Los Angeles County District Attorney.
Oct 18, 2016	Federal Interagency Task Force on Natural Gas Storage Safety issued its report, "Ensuring Safe and Reliable Underground Natural Gas Storage – Final Report."
Oct 21, 2016	CARB released report, "Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident."

Table ES-2: Summary of Recommendations

Observation	Recommendation
Section II: Agency Responses to Address Gas Leak Health Concerns	
Unified Command	A Unified Command should be formed early in response to a natural gas release, when human health and environmental threats are present and multiple jurisdictions are involved in the response effort. These jurisdictions could be represented by geographical boundaries, government levels (e.g., federal, state, local, tribal), functional responsibilities (e.g., fire, oil spill, emergency medical services), statutory responsibilities (e.g., Federal Land Managers, Responsible Party) or some combination thereof. The Unified Command should identify a liaison to the affected communities to ensure direct communication with affected residents.
Expert Advisory Group	In jurisdictions with significant natural gas storage, facility operators, regulatory and other responding agencies should consider compiling and maintaining a roster of potential subject-matter expert advisors. The Unified Command could consult the roster to quickly convene a group to provide decision makers with advice on complex technical issues. Such an advisory group would be separate from the technical experts that are a normal component of the typical Incident Command System.
Regulator Coordination and Regulatory Authority Review	Regulatory agencies at federal, state, and, as appropriate, local levels should review their existing authorities and regulations related to natural gas storage facilities to identify potential gaps and to address them in a collaborative manner that builds upon the existing state certification program for intrastate gas pipelines.
Section III: Ambient Air Pollutant Monitoring and Public Health Risk Assessment	
Monitoring Network	State and local monitoring agencies with natural gas storage facilities within their jurisdictions should have the ability to establish a robust ambient air monitoring network in the surrounding communities in order to adequately characterize the potential health impacts associated with natural gas leaks if resources are available. This includes access to real-time monitoring equipment for sulfur additive compounds, VOCs (hydrocarbons and aromatic compounds), SVOCs (e.g., naphthalene), methane, $PM_{2.5}$, H_2S, metals, and any other chemicals of concern identified by source data, as well as capability for instantaneous grab and 24-hour integrated samples.
Timeliness and Data Availability	State and local monitoring agencies should have an emergency air monitoring plan established to expeditiously deploy an ambient air monitoring network if a similar leak event were to occur. Having data early in the process would better enable agencies to reach timely decisions most consistent with public health protection (such as the decision to relocate residents). State and local monitoring agencies should also post their collected ambient air quality data in a prompt, easily accessible and easy-to-understand way.
Pollutants of Concern	State and local monitoring agencies in jurisdictions with natural gas storage facilities should consider collaborating with natural gas storage facilities to develop facility-specific chemical fingerprints of the natural gas. If kill attempts are considered for sealing a leaking well, the kill fluid should also be analyzed for metals and other potential pollutants of concern. Once these chemical fingerprints are known, targeted monitoring plans should be developed in order to facilitate a quick and targeted response to a leak event. Such a plan should prioritize sampling pollutants of greatest health concern, which could include benzene, toluene, ethyl benzene and xylenes (BTEX), $PM_{2.5}$ and hydrogen sulfide for air sampling.

Observation	Recommendation
Background Concentration of Pollutants	State and local monitoring agencies should consider collaborating with stakeholders to develop local background levels for methane and other pollutants of concern.
Health Effects	Further research is needed to determine the acute and chronic effects of exposure to natural gas odorants (t-butyl mercaptan and tetrahydrothiophene). Relevant agencies should review the results of the SoCalGas-funded study ordered by the SCAQMD Hearing Board and consider any relevant findings or recommendations. Monitoring and analysis by state and local agencies should continue and risk data should be updated if conditions change.
Coordination and Expertise	In the event of a future well leak, responding agencies should include health-related expertise in the response. Responding agencies should consider establishing a network of these health and risk assessment professionals prior to a leak event. After a leak has been identified, the network could be convened to meet regularly to assess collected air sampling data and the potential for health impacts from related pollutant exposures.
Detection Methods	Natural gas facilities, and local and state agencies, should consider identifying laboratories with the capability of measuring sulfur compounds at lower detection limits. If feasible, analytical methods to detect odorants at concentrations below odor thresholds should be used and available during incidents.
Source Testing and Characterization	State and local air monitoring agencies should consider developing systems to safely collect source samples during a release and consider conducting robust source testing/characterization. Information collected on the chemical constituents of sources could be used in conjunction with air dispersion and deposition modeling to help inform decisions.
Section IV: Greenhouse Gas Emissions	
Baseline Data	State and local air monitoring agencies should consider having a methane monitoring framework. Baseline methane measurements would improve understanding of the magnitude of a leak. The framework and measurements should build on data that are already reported to federal/state/local agencies.
Release Uncertainty and Multiple Measurements	State and local air agencies should begin methane monitoring as soon as possible following initial leak detection. All monitoring should be coordinated with attempts to stop the leak in order to determine if those attempts decrease, increase or stop fugitive methane emissions. When possible, future leaks from natural gas storage facilities should be measured with multiple methods to confirm measurements. State and local air agencies should consider coordination with existing measurement and quantification efforts, such as those by universities and federal and state agencies active in methane and other air emissions monitoring efforts. These entities may have data or experience with monitoring in the area that could be of use.
Measurement Technology	In advance of a leak, state emergency management agencies should determine whether they have access to aircraft and/or other mobile measurement technologies that can be rapidly deployed. Safety should be a consideration when flying in zones with high methane concentrations. Air agencies should also consider formalizing pilot projects involving state/local agencies, facility operators and federal agencies to deploy and evaluate some of the evolving methane measurement methods.
Inventory Tracking	Studies of natural gas releases should quantify emissions in such a way that they can be included in inventories. An emissions estimate of the total mass of gas emitted by an event can be directly included in an inventory, while methane

Observation	Recommendation
	concentration estimates at a given time cannot be included in an inventory without other information.
Section V: Post Well Closure Indoor Air and Source Sampling/CASPER Health Assessment	
Contaminant Identification	Given the evidence that materials used in well-kill fluids may be re-expelled and may contaminate the surrounding area, facility operators and emergency responders should use caution when determining the composition of the well-kill fluids and should consider the possible health risks that might result from exposure to toxic substances present in that fluid. Knowing the composition of the fluid would also facilitate environmental testing in the event of an accidental release. If a situation should occur where a large volume of kill fluid or other material is expelled along with natural gas, the appropriate state or local agency should test exposed homes for the presence of potential or known constituents before residents return. Soil samples taken at or near the source should be collected and analyzed for contaminants associated with the release, especially if residues resulting from a leak are found on or within structures at the facility or in a community and it is thought that these contaminants could pose a potential ingestion or inhalation risk. If enough information is known about the source and the expelled contaminants, dispersion modeling can be used to help make decisions regarding additional soil, surface water, and indoor sampling within the impacted community.
Source-Receptor Evaluation	Collection and analysis of source and ambient samples should be conducted to enable evaluations of links between receptors (such as ambient monitors and residential surface samples), emissions from the leak, and emissions from other, nearby emission sources; and to support evaluations of health risks associated with exposure to the mix of emitted constituents. A more in-depth analysis of multiple relevant source trace element ratios, the ratios of samples from receptor sites, and use of sequential extraction would be appropriate in more complex leak situations.
Post-Incident Sample Collection	Responding agencies should plan for post-incident sample collection and analysis, and integrate this plan into the initial incident response to help mitigate post-incident exposures and to compress post-incident timelines.
Home Cleaning	It is essential that in-home pollutant mitigation and cleaning activities only be performed by certified professionals under adequate supervision.
Public Health Hazard Assessment	State and local health and environmental agencies should consider developing standardized approaches for collecting health information and linking it with environmental monitoring data for use in public health hazard assessment if a similar leak event were to occur at other well sites.
Section VI: Greenhouse Gas Mitigation Plan	
Mitigating Releases of Short-lived Climate Forcers	States with underground natural gas storage should review their legal authorities to require greenhouse gas mitigation of fugitive emissions from underground natural gas storage facilities. States interested in mitigation should review California's approach as outlined in its Mitigation Plan.

I. Introduction

On October 23, 2015, the largest methane leak from a natural gas storage facility in United States history was discovered by the Southern California Gas Company (SoCalGas) at a well within its Aliso Canyon Underground Storage Field in Los Angeles County. On November 19, 2015, the Los Angeles Department of Public Health (LADPH) issued a Public Health Directive ordering SoCalGas to provide temporary relocation assistance to residents impacted by the natural gas leak at its Standard Sesnon-25 well site (SS-25). After numerous attempts to stop the leak, on February 11, 2016, SoCalGas reported that the leak had been temporarily sealed. On February 18, 2016, California state regulators confirmed that the leaking well had been permanently sealed.

Motivated by the events at Aliso Canyon, on April 1, 2016, the Obama Administration formed an Interagency Task Force on Natural Gas Storage Safety to better understand the overall safety and environmental impacts of our nation's natural gas storage infrastructure. Congress codified the Task Force through the Securing America's Future Energy: Protecting our Infrastructure of Pipelines and Enhancing Safety Act of 2016 (PIPES Act). The Department of Energy (DOE) and Department of Transportation (DOT) co-chaired the Task Force. Congress directed the Task Force to review the Aliso Canyon events and make recommendations to reduce the probability, and minimize the impacts, of any future occurrence of similar incidents at any of the approximately 400 natural gas storage facilities across the country. The Task Force was directed to assess three areas of concern arising from the Aliso Canyon incident: the physical integrity of natural gas storage facilities, the reliability of natural gas supplies, and the public health and environmental impacts of the release.[3]

The public health and environmental impacts were evaluated by a subgroup of the Task Force, consisting of staff from the Environmental Protection Agency, the Centers for Disease Control and Prevention, the Department of Transportation/Pipeline Hazardous Materials Safety Administration, and the National Oceanic and Atmospheric Administration. During the course of the evaluation, the Public Health and Environment Subgroup consulted with staff from state and local agencies involved in responding to the leak, including the South Coast Air Quality Management District (SCAQMD), the Los Angeles Department of Public Health (LADPH), the Los Angeles County Fire Department/Hazardous Materials Division (LA County Fire/HazMat), the California Air Resources Board (CARB), the California Natural Resources Agency/Department of Conservation/Division of Oil, Gas and Geothermal Resources (DOGGR), the California Office of Environmental Health Hazard Assessment (OEHHA) and the California Public Utilities Commission (CPUC).

This report summarizes and analyzes the actions taken to understand and address impacts to public health and the environment from the Aliso Canyon leak. Section II focuses on the actions

[3] On October 18, 2016, the Task Force issued its final report, "Ensuring Safe and Reliable Underground Natural Gas Storage," which summarizes the findings and recommendations made by each of three working groups convened by the Task Force. The report can be found at http://energy.gov/downloads/report-ensuring-safe-and-reliable-underground-natural-gas-storage.

taken by local, state and federal agencies to respond to the leak, including: (1) orders from state and local agencies to SoCalGas to relocate residents of the nearby community, to stop the leak, and to reduce its impact; (2) the federal government's convening of an incident-specific National Response Team (NRT) to coordinate the Federal agency response to the incident and EPA's activation of its Regional Response Team under the National Contingency Plan;[4] and (3) the formation of a Unified Command to direct the response and make decisions on how to stop, or "kill," the leak. In Section III, air quality monitoring, health risk assessments, and consideration of health symptoms reported by the public are discussed, spanning the time period from the leak's discovery through the closure of the well in February, 2016. Section IV summarizes the multiple efforts to quantify the release of greenhouse gas emissions from the leak. Section V describes the responses to public health complaints from residents as they began returning home, how the home environments were tested to assess exposures to pollutants of concern, and efforts to determine whether the reported symptoms were the result of the leak. Section VI summarizes actions taken to mitigate the climate effects associated with the greenhouse gases leaked into the atmosphere.

In each section, the summary of actions is followed by an analysis, structured as observations drawn from the response, discussions and recommendations. The recommendations are designed to inform facility operators and federal, state and local agencies with natural gas storage facilities within their jurisdictions of actions they may take to be prepared for the public health and environmental impacts of an incident similar to the Aliso Canyon release. A list of the recommendations may be found in Table ES-2.

II. Agency Responses to Address Gas Leak Health Concerns

A. Summary of Actions Taken

Background

On October 23, 2015, an uncontrolled release of natural gas was discovered by the SoCalGas at the Aliso Canyon Natural Gas Storage Facility (Aliso Canyon facility), in the northern San Fernando Valley, Los Angeles County, California. SoCalGas uses an abandoned oil reservoir at the Aliso Canyon facility as storage for natural gas. Natural gas is injected into the old sandstone reservoir formation at approximately 8,200 feet below ground surface for storage, and withdrawn for transmission and sale in response to market conditions. SoCalGas, a subsidiary of Sempra Utilities, is the owner and operator of the Aliso Canyon facility.

The Aliso Canyon facility contains 115 gas withdrawal/injection wells. The well that was the source of the leak, SS-25, was converted for use as a gas storage well in June 1973. The

[4] The National Oil and Hazardous Substances Pollution Contingency Plan (NCP) provides the organizational structure and procedures for preparing for and responding to discharges of oil and releases of hazardous substances, pollutants and contaminants. 40 Code of Federal Regulations Part 300.

Aliso Canyon facility has a total working storage capacity of 86 billion cubic feet (bcf) of natural gas,[5] making it one of the largest natural gas storage facilities in the United States. The leak initially released approximately 53 metric tons of methane per hour, resulting in a total of approximately 1,300 metric tons of methane released every day. A monthly greenhouse gas output of this size is approximately equivalent to the annual greenhouse gas emissions from 200,000 cars. Multiple actions were taken to address the leak and associated health concerns before the leak was fully controlled on February 18, 2016.

Porter Ranch, a residential community of approximately 30,000 people, is located near the Aliso Canyon facility. The Porter Ranch properties nearest to SS-25 are located approximately one mile away and 1,200 feet below the leaking wellhead. Immediately after discovery of the leak, many residents began reporting odor complaints (related to mercaptans, the familiar sulfur-smelling odorant added to natural gas for safety) to various local and state agencies, including 911. The LA to the complaint and sent personnel to the scene. The responding personnel were informed of non-emergency circumstances of the incident at the gate of the facility by SoCalGas and departed. SoCalGas telephoned the LA on October 24, 2015, and reported that the incident should be resolved by 6:00 PM PST.

Many Porter Ranch community members experienced adverse health impacts in the days following the leak. On November 19, 2015, the LADPH determined that emissions from SS-25 had caused health symptoms in some Porter Ranch residents and ordered SoCalGas to provide temporary relocation to residents who desired to move.[6] In its directive to SoCalGas, LADPH noted that inhalation of methane in the outdoor environment was not thought to pose a direct health threat to community members, but indicated that the added mercaptans did pose a health threat to the community, by way of possible short term neurological, gastrointestinal and respiratory effects upon inhalation.

Initial Monitoring and Regulatory Actions

The South Coast Air Quality Management District (SCAQMD), one of the largest and most technologically sophisticated air pollution control agencies in the world, covers Orange County and the urban portions of Los Angeles, Riverside and San Bernardino Counties. SCAQMD started receiving odor complaints from Porter Ranch residents on October 24, 2015, and began ambient air quality monitoring soon thereafter. SoCalGas began its own air sampling effort on October 30, 2015. This monitoring, in addition to ambient air quality monitoring conducted by the CARB and other entities, is described in detail in Section III. On November 5, 2015, SCAQMD issued a "Notice to Comply" that required SoCalGas to take specific steps to abate the natural gas leak, monitor the leaking gas, and reduce the impacts of nuisance odors on the local community.[7] On November 10, 2015, SoCalGas provided a written response to the Notice

[5] The natural gas stored at Aliso Canyon is approximately 95% methane with the remaining portion consisting of non-methane hydrocarbons such as ethane. See *Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA*; Science, 18 March 2016, p. 1318

[6] http://publichealth.lacounty.gov/eh/docs/AlisoCanyon.pdf

[7] South Coast Air Quality Management District Notice to Comply E-26893, http://www.aqmd.gov/docs/default-source/compliance/aliso-cyn/so-cal-gas-aliso-canyon---notice-to-comply-e26893.pdf?sfvrsn=2

indicating its investigation of the events surrounding the incident and the ongoing response efforts.[8]

On November 7, 2015, the California Energy Commission (CEC) sponsored the first airborne methane sampling effort. Flights continued through February, 2016. On November 10, the National Aeronautics and Space Administration/Jet Propulsion Laboratory (NASA/JPL) conducted an onsite field survey of the Aliso Canyon facility, and began satellite imaging of methane plumes on November 13, 2015. Monitoring for methane is described in more detail in Section IV.

DOGGR and the CPUC had the most direct operational oversight at the Aliso Canyon facility. Pursuant to the federal Pipeline Safety Act, DOGGR had this oversight role because of its delegated authority from the Department of Transportation/Pipeline Hazardous Materials Safety Administration (DOT/PHMSA) to conduct regulatory oversight of underground natural gas storage facilities in California. In early November, DOGGR convened a panel of technical experts from the Lawrence Berkeley National Laboratory, Lawrence Livermore National Laboratory and the Sandia National Laboratory to provide independent expertise to assist the Division in monitoring and evaluating SoCalGas actions.

DOGGR issued two orders to SoCalGas, one on November 18, 2015 and a second one on December 10, 2015.[9] The November 18 order required SoCalGas to provide information on SS-25; the December 10 order required SoCalGas to develop plans to expeditiously capture the escaping gas, stop the leak and communicate with state and local regulators. The December 10 order also required SoCal Gas to provide access to the SS-25 site and information to a group of experts from the DOE National Laboratories (Lawrence Berkeley, Lawrence Livermore and Sandia) who were assisting DOGGR in evaluating SoCalGas' plans for stopping the leak. The CPUC also provided directives to SoCalGas regarding its response to the incident via a series of letters issued between December 2015 and February 2016. These letters requested a variety of information including: (1) data on gas withdrawal rates from the Aliso Canyon field; (2) how gas withdrawal was affecting the leak at SS-25; (3) the cost to SoCalGas of addressing the leak at SS-25; (4) the volume and cost of the leaked methane; (5) information on the surface gas capture system design; (6) the retention of records and preservation of evidence by SoCalGas and (7) assistance by SoCalGas to CPUC's third party that conducted a root cause analysis of the SS-25 failure.[10] The information collected by CPUC from SoCalGas informed the steps that were taken by state regulatory agencies to address the gas leak, investigate its root causes and model how an interruption in the operation of the Aliso Canyon facility might impact the availability and reliability of power generation in the Los Angeles Basin in 2016 and 2017.

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[8] See http://www.aqmd.gov/docs/default-source/compliance/aliso-cyn/1-19-16-clean-socal-gas---alison-canyon---proposed-findings-and-decision.pdf?sfvrsn=4, page 4, lines 1-3

[9] Emergency Order No. 1104; November 18, 2015, Provide Data Re: Aliso Canyon Storage Facility; Emergency Order No. 1106; December 10, 2015, Provide Data and Take Specified Actions Re: Aliso Canyon Storage Facility

[10] Letters from CPUC to SoCalGas, dated December 11, 2015, December 14, 2015, December 23, 2015, January 4, 2016; January 14, 2016; January 18, 2016; January 20, 2016, January 22, 2016 and February 2, 2016

The Los Angeles County Fire Department had an active operational presence with SoCalGas starting in November. They deployed a 'short Incident Management Team' to work with the SoCalGas Operation and Planning Sections, preparing Incident Action Plans and other documents, and reviewing operations. The California Office of Emergency Services (Cal/OES) was also present from the first weeks of the incident.

Initial Federal Actions

On December 4, 2015, PHMSA's Office of Pipeline Safety began to provide technical assistance to the CPUC on the leaking Well SS-25 at Aliso Canyon. On December 20, 2015, PHMSA began to participate in daily Incident Command calls led by SoCalGas. DOT/PHMSA conducted a site visit at Aliso Canyon on December 22, 2015.

The United States Environmental Protection Agency (EPA) became actively involved in the Aliso Canyon incident in early December at the request of the California Office of Emergency Services and entered into an informal, federal multi-agency coordinating group with DOT/PHMSA and DOE. On December 16, 2015, two EPA Federal On-Scene Coordinators (FOSCs) conducted a site visit at the Aliso Canyon facility with LA County Fire/HazMat. The EPA FOSCs' assessment concluded that SoCalGas appeared to have well-control experts with the appropriate knowledge in charge of the site operations. From early December 2015 to the cessation of on-site activities in February 2016, the EPA participated in multiple daily calls, briefings and updates with federal, state and local partners. Federal agencies included DOE, DOT/PHMSA, Department of Interior/Bureau of Safety and Environmental Enforcement (DOI/BSEE), and Department of Commerce/National Oceanic and Atmospheric Administration (DOC/NOAA).

In early December the FAA issued a Notice to Airmen (NOTAM) restricting pilots from flying aircraft within a half-mile radius of the Aliso Canyon storage facility. The restriction extended up to 2,000 feet above the surface. The flight restriction expired on March 8, 2016.

Operations to Plug SS-25

Starting in on October 24, 2015 and continuing until December 22nd, SoCalGas conducted seven separate "top kill" operations to stop the leak. [11] SoCalGas also began planning for the drilling of a relief well for a "bottom kill" operation, if needed. "Top kill" operations involve pumping heavy drilling muds, fluids and other material (together known as "kill fluids") into the leaking well in an attempt to plug the well from above. "Bottom kill" operations involve drilling a relief well to intercept the leaking well at depth and pumping drilling muds and cement through the relief well into the leaking well to seal the well.[12] None of the top kill operations were successful. After the failed first well kill attempt on October 24, SoCalGas retained the services of Boots & Coots, a wholly owned subsidiary of Halliburton, for assistance on October 25, 2015. Boots and Coots is a recognized expert in well control services.

[11] The seven top kill attempts occurred from late October to late December 2015 on the following days: October 24th; November 13th, 14th, 18th, 24th, and 25; and December 22.

[12] The fluids used contained calcium chloride polymers, barium sulfates, monocarboxylic acids and light petroleum distillates, all common constituents of drilling muds; the top kill attempt on November 13 introduced inert materials such as walnut shells into SS-25, along with weighted muds.

On November 25, 2015, SoCalGas began drilling a relief well in order to conduct a bottom kill operation. In early December 2015, SoCalGas began withdrawing natural gas from the Aliso Canyon facility at a rate of approximately one billion cubic feet per day (bcf/day), in an effort to reduce pressure around SS-25. SoCalGas also started preparing for a second relief well, should it become necessary. The first relief well was ultimately successful in plugging SS-25 and no other relief wells were drilled.

In at least one top kill attempt, significant volumes of kill fluids were expelled from the borehole by the escaping gas. Because the Aliso Canyon storage facility uses abandoned petroleum-bearing formations, the escaping gas also caused residual petroleum from these formations to become aerosolized and expelled from the well bore, resulting in the deposition of an oily residue on the outside of many Porter Ranch residences, vehicles and outside areas. It is believed that these unsuccessful top kill attempts partially aerosolized some kill fluid constituents, such as barium, and that these aerosolized products, in the form of an oily mist, were in turn carried in the air and deposited in the interior of some Porter Ranch residences. To mitigate this problem, starting on January 3, 2016, SoCalGas installed a series of metal screens, called coalescing trays, over SS-25 to contain this oily mist. See Section V for a discussion of the efforts to assess the presence of aerosolized pollutants within homes in the affected area, as well as efforts to clean the homes that were exposed to the oily mist.

In response to the December 10, 2015 order from DOGGR to develop plans for capturing the methane at the surface, SoCalGas submitted a permit application to the SCAQMD on January 4, 2016, to obtain approval for construction and operation of temporary equipment to capture and control natural gas from the leaking well. SoCalGas ultimately abandoned this effort, after several weeks of investigation and design work, due to significant safety concerns raised by LA County Fire and the company's well-control experts regarding the feasibility of constructing, installing and operating a gas capture system in a methane-rich environment.

On January 6, 2016, California Governor Jerry Brown issued a proclamation declaring a State of Emergency in Los Angeles County as a result of the natural gas leak at the Aliso Canyon facility. The Governor's emergency proclamation provided for "all state agencies to use personnel, equipment and facilities to ensure a thorough and continuous response to the incident, as directed by the Governor's Office of Emergency Services and the State Emergency Plan."[13] The emergency proclamation contained requirements for a number of state agencies, including the CPUC, the CEC, the CARB, OEHHA, the California Independent System Operator (CA ISO) and DOGGR regarding stopping the leak, protecting public safety, ensuring accountability and strengthening oversight of gas storage facilities.

Further Federal Action

On January 4, 2016, PHMSA and the EPA met to discuss the convening of a National Response Team (NRT) to coordinate the Federal agency response to the incident. The NRT is a

[13] Proclamation of a State of Emergency, January 6, 2016, by Governor Edmund G. Brown for the County of Los Angeles due to the natural gas leak

component of the National Response System (NRS) that consists of fifteen federal agencies specified in Section 300.175(b) of the National Oil and Hazardous Substances Pollution Contingency Plan (NCP) and is responsible for carrying out national response and preparedness planning, coordinating regional planning, and providing policy guidance and support to incident-specific Regional Response Teams (RRTs).[14,15] On January 7, 2016, the EPA activated its Regional Response Team 9 (RRT9). That same day, the EPA reported progress and updates to the DOT/PHMSA, DOE, the Federal Emergency Management Agency (FEMA) and (Cal/OES). On January 8, 2016, PHMSA and the EPA reported progress pertaining to the Aliso Canyon response to the White House National Security Council (NSC) Domestic Resilience Group (DRG). The EPA agreed to report back on the progress by state and local agencies to assess the short- and longer-term public health impacts of the release. SoCalGas Executives also briefed DOT at their headquarters. The full NRT convened on January 11, 2016, to discuss the Aliso Canyon incident.

On January 11, 2016, RRT9 briefed the NRT on the Aliso Canyon incident. RRT9 requested that the NRT convene a federal interagency panel of well-control experts to advise and consult on the safety and operation of the gas capture and disposition system being proposed by SoCalGas, which would have captured the leaking natural gas at the surface of SS-25. The gas capture system was essentially a giant, inverted funnel and flare system that would capture the gas escaping at the surface, direct it away from the well head through pipes and incinerate it. As noted above, this proposal to capture and incinerate the leaking gas was ultimately abandoned due to significant safety concerns.

PHMSA leadership met with the CEOs from American Petroleum Institute, American Gas Association, and the Interstate Natural Gas Association on January 15, 2016, to discuss the industry's response efforts and encourage its support to SoCal Gas with technical assistance and to ensure the industry was reviewing underground storage safety across the country.

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[14] 40 CFR Part 300. The NCP, which is authorized by the Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA), the Clean Water Act § 311, and the Oil Pollution Act of 1990 (OPA), provides, among other authorities, an organizational structure and procedures, known as the National Response System (NRS), for responding to discharges and substantial threats of discharges of oil and substantial threats of releases of hazardous substances, pollutants, and contaminants.

[15] The NRS is an organized network of agencies, programs, and resources with authorities and responsibilities in oil and hazardous materials preparedness and response at the local, state, tribal, territorial, insular area, and Federal levels. Key federal response components of the NRS include the National Response Center, Federal On-Scene Coordinators (FOSCs), 13 Regional Response Teams (RRTs), and the National Response Team (NRT). The RRTs and NRT are key regional- and national-level multiagency coordination groups, led by the EPA and Department of Homeland Security/US Coast Guard (DHS/USCG), which provide support to the FOSC as needed during incidents, including interagency technical assistance and resource support. The RRTs and NRT include representatives from 13 additional Federal agencies that provide oil and hazardous materials expertise and support, and some have specific responsibilities for natural resource protection. The two principal components of the RRT mechanism in the NRS are a standing team, which consists of designated representatives from each participating federal agency, state governments and local governments (as agreed upon by the states); and incident specific teams formed from the standing team when the RRT is activated for a response. On incident specific teams, participation by the RRT member agencies will relate to the technical nature of the incident and its geographic location. (40 CFR § 300.115).

Starting on January 20, 2016, PHMSA's Office of Pipeline Safety Emergency Support and Security Division began leading an ad-hoc Federal Government information exchange group. The group included career representatives from the EPA (HQ and Region), DOE, DOI/BSEE, and PHMSA. The group met on a weekly basis until it was confirmed that the well was permanently sealed. PHMSA provided an in person briefing for the Senate Climate Change Task Force on January 20, 2016.

On February 5, 2016, PHMSA published an advisory bulletin entitled "Safe Operations of Underground Storage Facilities for Natural Gas." The bulletin reminded all owners and operators of underground storage facilities used for the storage of natural gas (as defined in 49 CFR Part 192) to consider the overall integrity of the facilities to ensure the safety of the public and operating personnel, and to protect the environment.

Public Meeting with State Leadership

On January 15, 2016, the State of California convened a public meeting in Porter Ranch. In attendance were a number of state leaders, representatives of EPA Region 9, and approximately 1,200 community members.[16] The state leaders gave an overview of their agencies and authorities, and described the actions their agencies had taken thus far in the response to the gas leak at Aliso Canyon, including issuing orders to SoCalGas that required abatement of the leak and relocation of residents, establishing air monitoring stations, estimating the amount of methane being released and requiring SoCalGas to maximize withdrawals of gas from the Aliso Canyon facility. The audience asked questions about which communities were being affected by the gas leak and how short- and long-term effects on the communities would be addressed. Members of the public said that SoCalGas should be held responsible for correcting the current problem, upgrading its infrastructure to prevent future releases, and compensating the residents without a rate increase. Many in the audience said that the Aliso Canyon facility should be closed.

Several other meetings took place between community members and agency leads during the leak in an ongoing effort to communicate with the impacted community.

Formation of Unified Command and Bottom Kill Planning

By November 2, 2015, SoCalGas had established an Incident Command with daily briefings about the leak at well SS-25. The Incident Commander designation revolved between several senior officials from SoCalGas, including Jimmie Cho, Senior Vice President for Gas Operations and Systems Integrity. It was not until January 22, 2016, that the SoCalGas incident command transitioned into a Unified Command (UC) with Los Angeles County Fire Department and the LADPH. As a component of the Incident Command System (ICS), the UC is a structure that brings together the individual Incident Commanders of all major organizations involved in the incident to coordinate an effective response, while at the same time carrying out their own

[16] State leaders present included Director of the Office of Emergency Service Mark Ghilarducci, Public Utilities Commission President Michael Picker, Natural Resources Agency Secretary John Laird, California Environmental Protection Agency Secretary Matthew Rodriquez, California Air Resources Board Executive Officer Richard Corey, California Energy Commission Chief Deputy Director Drew Bohen, Department of Conservation Chief Deputy Director Jason Marshall and OEHHA Acting Director Lauren Zeise. Elected officials present included Los Angeles City Councilman Mike Englander, State Senator Fran Pavley, State Assembly Member Scott Wilk and Congressman Steve Knight.

jurisdictional responsibilities. The UC links the organizations responding to the incident and provides a forum for these agencies to make consensus decisions. This was a significant organizational change that provided the local agencies with much greater control over on-site actions and improved communication to the public. PHMSA and the EPA participated in daily briefings with the UC. The CPUC ordered SoCalGas on January 21, 2016, to continue withdrawing gas from the Aliso Canyon storage field until it reached 15 bcf of working gas. The withdrawal of natural gas from the Aliso Canyon storage field was intended to reduce the pressure at the field and therefore minimize the rate of the gas leak. The remaining 15 bcf of working gas was to ensure energy reliability on high demand days. On January 23, 2016, SoCalGas had all wells shut off from withdrawal.

On February 8, 2016, the EPA participated in a federal interagency call with PHMSA, the DOE and the DOI. The EPA solicited technical help from well-drilling experts in DOI's BSEE to evaluate the drilling and bottom kill plans for SS-25. A second DRG call was held on February 11 with the White House National Security Council staff, during which the EPA provided information about the status of the Aliso Canyon bottom kill operation.

On February 16, the Administrator of PHMSA, Marie Therese Dominguez, and the Secretary of DOE, Ernest Moniz, visited the Aliso Canyon release site and participated in a government only roundtable with key federal, state, and local agencies involved in the response to the leak at Aliso Canyon.

On February 18, 2016, DOGGR issued a determination that SS-25 had been permanently sealed. This determination was preceded by a "soft touch" encounter between the relief well and SS-25 on February 10, wireline logging and testing to make sure that the relief well was properly oriented to conduct the bottom kill operation, a milling operation to establish communication between the relief well and the target well and pumping in mud and cement to seal the well.

The UC for the Aliso Canyon incident stood down on February 19, 2016, when the CPUC began its lead role in the investigation phase of the incident. On September 13, 2016, SoCalGas agreed to pay $4 million to settle criminal charges filed by the Los Angeles County District Attorney alleging misdemeanor violations for neglecting to report the release of hazardous materials and releasing air contaminants.

B. Observations, Discussion and Recommendations

1. Unified Command

Observation: During the initial leak period, a number of regulatory and emergency response agencies were involved in addressing various aspects of the leak, including public health and environmental impacts, well-control operations, community involvement, media communications and public outreach. However, SoCalGas was acting as the single incident commander during this time.

Discussion: For 92 days, from discovery of the leak at well SS-25 until January 22, 2016, SoCalGas acted as the incident commander. On January 22, 2016 SoCalGas, LA County Fire/HazMat and LADPH formally entered into a Unified Command (UC). Entering into a UC

earlier might have improved the response in terms of environmental and public health messaging and communication with external parties.

Generally, during emergency responses, the responsible party (in the case of the Aliso Canyon incident, SoCalGas) and the appropriate federal, state and local agencies should enter into a UC when it is clear that response decisions will affect multiple jurisdictions in terms of statutory authority, functional responsibility, or material or significant impacts. In this situation, the UC appropriately included SoCalGas, LA County Fire/HazMat and LADPH. The command structure could have also included representatives from DOGGR, CPUC, CalEPA, and SCAQMD as cooperating agencies. In the Aliso Canyon response, establishing a UC brought safety, logistics, management, cooperating agency and planning elements into the ICS organization. Including additional partners would ensure that the relevant agencies are sharing other appropriate information with the UC and conferring/cooperating before taking independent action. Entering into a UC earlier, with the participation of relevant cooperating agencies, would have enabled clearer and more consistent communication among the agencies and with the public about the progress in understanding the potential public health impacts of the release.

Recommendation: A Unified Command should be formed early in response to a natural gas release, when human health and environmental threats are present and multiple jurisdictions are involved in the response effort. These jurisdictions could be represented by geographical boundaries, government levels (e.g., federal, state, local, tribal), functional responsibilities (e.g., fire, oil spill, emergency medical services), statutory responsibilities (e.g., Federal Land Managers, Responsible Party) or some combination thereof. The Unified Command should identify a liaison to the affected communities to ensure direct communication with affected residents.

2. Expert Advisory Group

Observation: SoCalGas mobilized crews and equipment immediately upon discovery of the leak and, within 24 hours, determined that its standard procedures to abate leaks were not working and called in additional experts. Within 48 hours, SoCalGas had well-control experts on-site.

Discussion: EPA Region 9 staff made several visits to the SS-25 well site and participated in a number of meetings with state and local agencies and other federal agencies, as well as meetings that included SoCal Gas representatives. EPA Region 9 staff also consulted with an ad-hoc federal interagency group that included DOT/PHMSA, DOI/BSEE, DOE and EPA headquarters offices, including the Office of Research and Development and the Office of Land and Emergency Management. EPA Region 9 found that by the time it became involved, SoCalGas had brought in the needed well-control experts for advice on how best to control well SS-25. However, in any potentially adversarial situation, it is helpful for regulators to have objective advice from their own experts who can advise on the potential pitfalls from a specific course of action. For example, the DOI/BSEE drilling engineers that EPA consulted with were invaluable in advising on the efficacy of SoCalGas' bottom kill plan, as they had a wealth of experience from their work with oil and gas drilling in the Gulf of Mexico.

The issues under consideration during the Aliso Canyon incident were complex and wide-ranging and included subjects such as well-control techniques, public health effects of exposure to mercaptans or other chemicals, the environmental impact of a greenhouse-gas release of this

magnitude, public communication and regulatory oversight. It is essential that decision makers have access to accurate and complete information to make well-informed decisions. A readily accessible group of subject-matter experts might have improved the decision making process. This is especially true for the complex engineering and health and safety issues associated with top kill attempts and surface gas collection.

Recommendation: In jurisdictions with significant natural gas storage, facility operators, regulatory and other responding agencies should consider compiling and maintaining a roster of potential subject-matter expert advisors. The Unified Command could consult the roster to quickly convene a group to provide decision makers with advice on complex technical issues. Such an advisory group would be separate from the technical experts that are a normal component of the typical Incident Command System.

3. Regulator Coordination and Regulatory Authority Review

Observation: In the Aliso Canyon incident, local and state agencies in California had an existing regulatory framework and adequate authority and expertise to respond effectively to the incident. Federal agencies provided additional expertise and support for the state response efforts. However, this is not true across the country or for interstate gas storage facilities. This lack of uniformity prompted Congress, PHMSA, the gas storage industry, and state regulators (generally oil and gas boards) to examine the need for federal and state regulators to work together more closely to produce a more effective and seamless set of safety standards and regulations.

Discussion: Federal agencies such as the EPA and PHMSA have assessed their respective regulatory and injunctive authorities. It was determined that in this case, state and local authorities were fully engaged, had adequate authority, and were ordering similar relief to what federal authorities would have pursued.

However, in the event of a release from an interstate facility or in other states, there is currently no set of mandatory safety standards that can be uniformly enforced across the country. Under PHMSA's state certification program for intrastate gas pipelines, states voluntarily file annual certifications with PHMSA, representing that they have the adequate authority and resources to effectively inspect intrastate pipelines and enforce the applicable requirements. This state certification program is currently in place in 48 states, under which program PHMSA monitors state programs and provides federal funding. To the extent state oil and gas agencies other than the state pipeline safety agency will be responsible for the wells and downhole facilities, these agencies may also need to become certified. In June 2016, Congress directed PHMSA to move forward expeditiously with adopting minimum safety standards for underground storage, a process which is currently underway. In addition, other federal agencies may need to fill gaps and order additional relief to ensure that public health and the environment are protected.

Recommendation: Regulatory agencies at federal, state, and, as appropriate, local levels should review their existing authorities and regulations related to natural gas storage facilities to identify potential gaps and to address them in a collaborative manner that builds upon the existing state certification program for intrastate gas pipelines.

III. Ambient Air Pollutant Monitoring During the Incident and Public Health Risk Assessment

A. Summary of Air Monitoring Actions and Health Risk Assessment

The responding parties needed to understand what pollutants were emitted during the period of the leak, and at what concentrations, in order to assess possible effects on public health. Air quality monitors were deployed and data were collected, quality assured, and analyzed. The data were then made available to public health experts for comparison with known health benchmarks to assess the potential health risks to the exposed population. This section first summarizes the actions taken to measure the concentrations of ambient air pollutants during the period of the leak and then summarizes the actions taken to interpret these data in terms of health risk.[17]

State and local air pollution control agencies have the primary responsibility for conducting ambient air monitoring within their jurisdictions, including monitoring for emergency response. The EPA provides funding and oversight to enable these agencies to accomplish these objectives. The two air pollution control agencies that conducted emergency ambient air monitoring in response to the Aliso Canyon natural gas leak were SCAQMD and CARB. SoCalGas and the Los Angeles Unified School District (LAUSD) also collected ambient air samples on facility property and in the Porter Ranch community. Later during the response, and on its own initiative, the University of California at Los Angeles (UCLA) conducted ambient air monitoring.

Discrete Sampling

A series of discrete sampling efforts was conducted beginning on October 26, 2015. The first samples were taken by SCAQMD in direct response to the first community complaints received on October 24, 2015, the day after the leak was detected. Following this initial sampling, numerous other samples were taken for a wide variety of pollutants. In addition to the discrete sampling, continuous monitoring was established for a small set of pollutants at fixed monitoring sites, which is described in the next section (see Figure 1 for a map of SCAQMD and CARB sampling and monitoring locations).

The monitoring objectives for the ambient air monitoring of pollutants were generally threefold: (1) to assess potential exposure to various pollutants determined to be of concern, (2) to evaluate the extent of the emissions transport into the surrounding area, and (3) to provide information to Porter Ranch community members. One study monitored air quality at twenty schools in the area near the leak to assess students' exposure to pollutants of concern associated with the leak. Most of the sampling was done in and around the Aliso Canyon Facility but

[17] We note that monitoring can serve different purposes. This report addresses monitoring that was conducted to assess human exposure to chemicals emitted by the leak as well as the environmental impacts associated with escaping GHG emissions. The report covering the physical integrity of natural gas storage facilities addresses monitoring for the prevention, detection, and repair of leaks at natural gas storage facilities.

monitoring was also conducted in a separate area in order to re-verify potential pollutants of concern within the community compared to a background location.[18] Finally, indoor air was also sampled for radon to determine whether levels exceeded EPA's action level, due to concerns about the potential presence of radon in the released natural gas.

The monitoring methods described in this section include:

- Instantaneous grab samples[19] and 12- and 24-hour canister samples that can collect over 50 volatile organic compounds (VOC), semivolatile organic compounds (SVOCs), polycyclic aromatic hydrocarbons (PAHs), metals, carbon monoxide, carbon dioxide, methane, ethane, non-methane non-ethane organic carbon, and sulfur species. Samples can be collected with canisters or Tedlar bags.
- Liquid scintillation activated charcoal canisters, which can be used to measure radon.

[18] https://www.alisoupdates.com/1443738525764/Facility-Supplemental-Sampling-Summary__02_15.pdf

[19] Also referred to as short-term air samples, instantaneous grab samples are typically 10-minute samples used to assess air quality at a particular point in time, thus giving a very time resolved understanding of the ambient air, which then can be used to address specific community complaints or concerns.

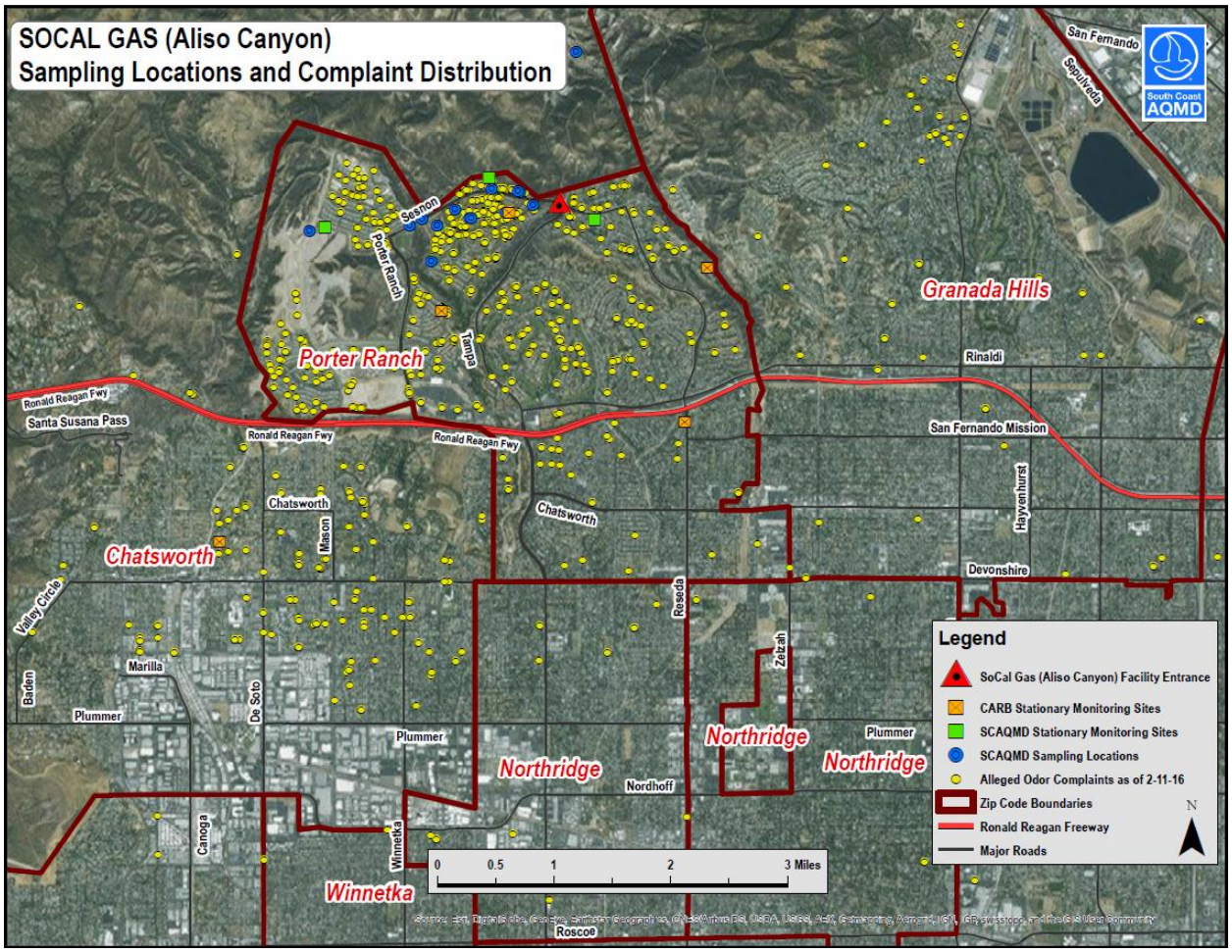

Figure 1: SCAQMD and CARB Sampling/Monitoring Locations[20]

The detailed information on the collection and analysis of the canister, tedlar bag, radon, and instantaneous grab samples described above is summarized in Table 1.

[20] Source: Aliso Canyon Facility Monitoring Network Plan, p.3

Table 1: Summary of Sampling Methods and Analysis

Agency/ Location (# Sites)	Sample Date(s) / Duration	Sample Method	Pollutants	Analytical Lab	Analytical Method
SCAQMD / Porter Ranch Community (10)	10/26/15 – 2/4/16 Instantaneous grab sample	SUMMA canisters[21]	VOCs, methane, CO, CO_2, ethane	SCAQMD	EPA TO-14[22], EPA TO-15[23], EPA Method 25.1[24]
SCAQMD	Instantaneous grab sample	Tedlar bags[25]	Sulfur species	SCAQMD	SCAQMD Method 307-91[26]
SoCalGas / Aliso Canyon facility property (14) and Porter Ranch Community (24)	10/30/15 – 3/19/16 Instantaneous grab sample	SUMMA canisters	VOCs, methane, sulfur species	Atmospheric Analysis and Consulting Inc (AtmAA)	EPA TO-15, modified EPA 18[27]
LAUSD / Schools near Porter Ranch Community (20)	11/30/2015 – 2/22/2016 8-hour and instantaneous grab sample	SUMMA canisters	VOCs, methane, sulfur species	Quantum Analytical Services Inc	SCAQMD Method 307-91, EPA-18, EPA Method TO-14
LAUSD / Classrooms and offices in Porter Ranch Community and Castlebay Lane Elem. School (50)	12/4/2015 – 12/10/2016	Liquid scintillation activated charcoal canisters	Radon	Accustar Laboratory	
SCAQMD /	12/17/2015		aromatic volatiles, total		

[21] Stainless steel containers that are under vacuum and when the valve is opened, the air sample is drawn into the canister

[22] https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-14ar.pdf

[23] https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-15r.pdf

[24] https://yosemite.epa.gov/R9/R9Testmethod.nsf/0/5832DB3C67E181A78825709300656AF6/$file/200510112745767394902STOG6GXPND.pdf

[25] teflon/milar bags that are filled with air using a small pump

[26] http://www.aqmd.gov/docs/default-source/laboratory-procedures/methods-procedures/307-91.pdf?sfvrsn=2

[27] https://www3.epa.gov/ttn/emc/promgate/m-18.pdf

Agency/ Location (# Sites)	Sample Date(s) / Duration	Sample Method	Pollutants	Analytical Lab	Analytical Method
near well SS-25 (1)	Instantaneous grab sample		volatiles for carbon (C_3 to C_{12})		
SoCalGas / Various locations around Aliso Canyon facility and fenceline	1/2015 – 3/2016 12-hour	6.0 liter Silonite canisters	VOCs, methane, sulfur species	ALS Environmental	EPA TO-3[28], EPA TO-15, ASTM D 5504-12[29].
SoCalGas / Aliso Canyon facility	1/19/2016 7-day		Radon	ALS Environmental	
SoCalGas / Aliso Canyon facility (3)	1/2015 – 3/2016 12-hour	6.0 liter Silonite canisters	VOCs, SVOCs, PAHs, metals	ALS Environmental	EPA TO-15, EPA TO-13[30], and EPA 6020[31]
UCLA / Porter Ranch Community (23) and background (1)	1/13/2016 – 1/28/2016		VOCs, gaseous contaminants, and size-fraction particles		
SoCalGas 2/3/2016	12-hour	6.0 liter Silonite canisters	VOCs, methane, sulfur species,	ALS Environmental	EPA TO-3, ASTM D 5504-12, and EPA TO-15
SoCalGas 3/3/2016	24-hour	6.0 liter Silonite canisters	VOCs	ALS Environmental	EPA TO-3 and TO-15

Each monitoring entity was responsible for reporting its own data. All agencies were committed to providing results to the public quickly and in a transparent and understandable way. Results from the SCAQMD samples were posted on its website as soon as the laboratory analysis was complete, within two to four days after sampling.[32] The results from SoCalGas

[28] https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-3.pdf
[29] https://www.astm.org/Standards/D5504.htm
[30] https://www3.epa.gov/ttnamti1/files/ambient/airtox/to-13arr.pdf
[31] https://www.epa.gov/sites/production/files/2015-07/documents/epa-6020a.pdf
[32] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-sampling/laboratory-results---air-sampling-data

sampling were summarized on the SoCalGas website under "air sample summary," which included detailed lab reports for each sample. The results for samples collected by LAUSD were posted on the LAUSD website.[33,34]

Fixed Continuous Monitoring Sites

In December 2015, SCAQMD and CARB began to deploy a network of eight fixed ambient air monitoring sites throughout the Porter Ranch community to continuously measure methane, hydrogen sulfide (H_2S), total sulfur, and benzene (See Figure 2)[35] in order to develop a baseline for various measurements and track the trends of pollutants throughout the leak event. The fixed locations allowed the agencies to collect reliable continuous measurements that provided a useful supplement to the discrete samples, which occurred at different locations throughout the community and provided only a snapshot of air quality during a particular sampling period. Methane and meteorological measurements were also collected at the SCAQMD's Reseda State and Local Air Monitoring Station (SLAMS)[36] monitoring site, located 3.5 miles to the south. Results from the continuous monitors were posted on the SCAQMD and CARB websites in near-real time.

[33] http://achieve.lausd.net/Page/4244

[34] http://achieve.lausd.net/cms/lib08/CA01000043/Centricity/Domain/135/LAUSD_Radon_Testing_Report_MD.pdf

[35] Slide 21, Federal Task Force – Aliso Canyon Presentation – June 9, 2016. Presented by Mohsen Nazemi, P.E., Deputy Executive Officer, Engineering and Compliance, SCAQMD to the Public Health and Environment Workgroup on June 9, 2016.

[36] SLAMS monitoring sites are part of the national ambient air monitoring network that typically measure the six criteria pollutant (Particulate matter, lead, ozone, nitrogen oxides, sulfur oxides, and carbon monoxide) in accordance with federal regulations contained in 40 CFR part 50 and 58.

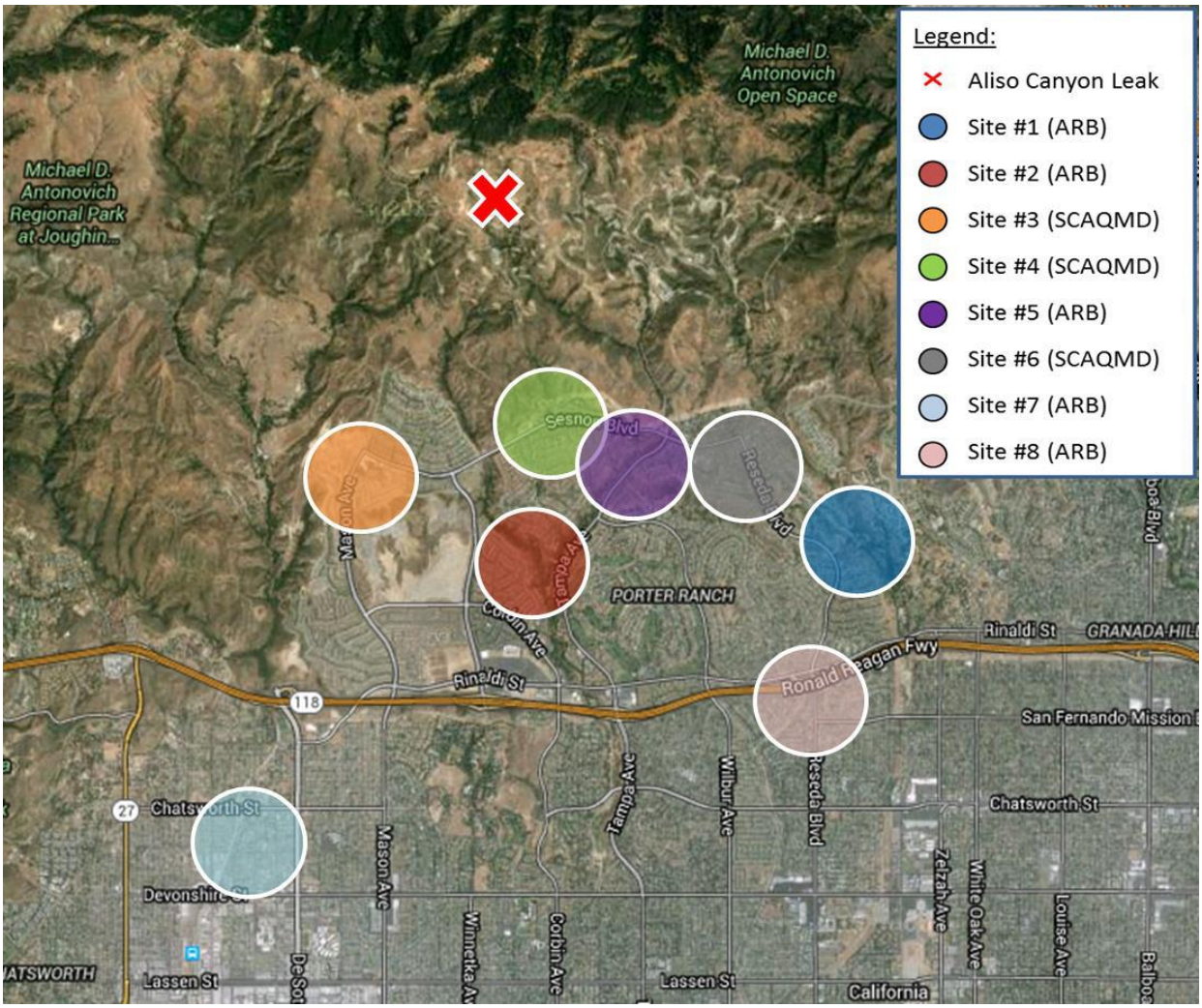

Figure 2: Map of Fixed Monitoring Locations[37]

All the CARB sites were located at residential properties in the community, while the SCAQMD sites were located at the Porter Ranch Community School (Site #3), Highlands Community Pool (Site #4), and the Castlebay Lane Charter School (Site #6). Table 2 provides a matrix of which pollutants were measured at each site as well as the instrument and measurement method used for each pollutant.

[37] Source: Aliso Canyon Facility Monitoring Network Plan, p.9

Table 2: Summary of Fixed Monitoring Sites in the Porter Ranch Community

Site	Agency	Methane	Methane/Non-Methane Hydrocarbon	Methane/H_2S	Benzene	Total Sulfur[38]
1	CARB	Picarro 2301 (cavity ringdown spectroscopy)	n/a	n/a	n/a	n/a
2	CARB	Picarro 2301 (cavity ringdown spectroscopy)	n/a	n/a	n/a	n/a
3	SCAQMD	n/a	Mocon Analyzer (FID)	Picarro G2204 (cavity ring spectroscopy)	n/a	Ecotech (chemilumiscence)
4	SCAQMD	n/a	Thermo Model 55c (FID)	Picarro G2204 (cavity ring spectroscopy)	n/a	Ecotech (chemilumiscence)
5	CARB	LGR RMT-200 (Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS)	n/a	n/a	IO Analytical (GC FID)	n/a
6	SCAQMD	n/a	Mocon Analyzer (FID)	Picarro G2204 (cavity ring spectroscopy)	n/a	Ecotech (chemilumiscence)
7	CARB	LGR RMT-200 (Off-Axis Integrated Cavity Output Spectroscopy (OA-ICOS)	n/a	n/a	IO Analytical (GC FID)	n/a
8	CARB	Picarro 2201i (cavity ring spectroscopy)	n/a	n/a	n/a	n/a

Additionally, 24-hour integrated canister samples were collected at the three SCAQMD fixed sites (sites #3, 4, 6) and an additional nine locations throughout the area. Three of these additional sites were within the SoCalGas facility, three were located on the perimeter of the SoCalGas facility, and three were located within the Porter Ranch community. Initially, instantaneous grab samples were also collected at the SCAQMD monitoring sites if the continuous methane monitor at site #4 measured concentrations greater than 30 ppm or the

[38] Total sulfur measurements include detection of odorizing compounds tetrahydrothiophene (THT) and t-butyl mercaptan

methane monitors at sites #3 and site #6 measured concentrations above 20 ppm. The trigger levels were set after an evaluation of general levels compared against peak levels to ensure that the grab samples appropriately were triggered during peak concentration hours at each location. After February 18, 2016, when the leak had been permanently sealed, the trigger levels were lowered to 5 ppm at all three locations to account for the drop in methane concentrations observed in the community.[30]

To ensure the data collected during the SoCalGas natural gas leak were accurate and of robust quality, both CARB and SCAQMD implemented quality assurance and quality control checks throughout the monitoring network on a regular basis and performed on-site visits for routine maintenance of the instruments. The continuous benzene instruments operated by CARB received bench calibrations at CARB's Monitoring and Laboratory Division's (MLD) laboratory and calibration in the field when they were installed. Similarly, continuous methane instruments operated by CARB, were calibrated prior to deployment and instrument responses were checked against NIST traceable standards in the field. Continuous methane instruments operated by SCAQMD were checked with a known concentration using a certified gas cylinder and were calibrated on a weekly basis. A week-long side-by-side comparison was also performed between various methane instruments to check for instrument variability and potential bias between measurements and laboratory analysis.

SCAQMD also developed an "Aliso Canyon Facility Monitoring Network Plan" that describes current and future monitoring.[39] The plan describes a phased approach (Phase 1 – Phase IV) to the ongoing monitoring in the community with specific dates and conditions for moving to the next phase. Generally, the move to each phase is contingent upon "continued measurements showing typical ambient levels of pollutants" and "no other species or operational activity to cause concern for community impacts" and is associated with a gradual reduction of certain measurements for both the continuous monitors and 24-hour integrated samples. This approach ensures continued measurement of various pollutants while other measurements are discontinued if ambient concentration return to typical levels for a predetermined amount of time and there are no changes to SoCalGas operations that would warrant continued monitoring.

Mobile Methane Monitoring

In addition to the eight fixed monitoring sites, SCAQMD operated a mobile monitoring platform measuring methane concentrations[40] in order to better characterize methane concentrations and track emissions transport within the community and surrounding area. While methane itself is not harmful unless it is above flammability limits or is present in such high concentrations that it displaces the oxygen needed to breathe (generally only in confined spaces), methane measurements throughout the community served as markers for areas with high emissions that could potentially include other pollutants. Mobile methane measurements began on December 21, 2015 and were performed during different times of the day under varying meteorological conditions. Each mobile monitoring run ranged from 15 minutes to multiple hours and generally followed a unique path throughout the area, including several measurements

[39] http://www.aqmd.gov/docs/default-source/compliance/aliso-cyn/aliso-canyon-monitoring-plan.pdf?sfvrsn=4
[40] LI-COR 7700 open path instrument and a Global Positioning System (GPS) mounted on a hybrid vehicle

in the vicinity of the community's schools. Mobile monitoring continued until May 7, 2016, with 29 runs occurring before the leak was stopped and 44 afterwards. Prior to deployment, a comparative side-by-side analysis of the mobile monitoring platform methane instruments and fixed site instruments was performed to check for instrument variability. Concentrations for each mobile monitoring run were then mapped and uploaded to the SCAQMD website.[41]

Methane emissions were also qualitatively observed with a Forward Looking Infrared (FLIR) thermal camera, which allowed SCAQMD and CARB to identify the plume of fugitive emissions and eventual leak closure in areas near Well SS-25. As with the mobile measurements taken within the Porter Ranch community, the FLIR images were uploaded to the SCAQMD and CARB websites.[42]

Summary of Results of Ambient Air Pollutant Monitoring

Final reports from the various ambient air monitoring studies have not yet been released but some preliminary results are available from SCAQMD[43] and OEHHA.[44] The collective studies found higher levels of certain air pollutants in some instantaneous samples in the Porter Ranch community. These same air pollutants were identified in a sample taken about 10 feet from the SS-25 well.

The VOC concentrations did not exceed any available acute Reference Exposure Levels (RELs), which are concentrations of chemicals in the air that the general public can be exposed to without experiencing health problems.[45] Of the VOCs, benzene levels tended to be highest and most closely approached the corresponding acute REL. The sample with the highest levels of benzene (3.0 ppb) and other air toxics measured by SCAQMD, out of more than 70 instantaneous community samples, was collected on October 26, 2015 on Kilfinan Street in Porter Ranch, between Turtle Ridge Way and High Glen Way, by SCAQMD.[46] Using the concentrations from this sample, SCAQMD calculated the acute health risk as approximately one-third of the REL. SoCalGas reported measuring the highest benzene levels (5.55 ppb) on November 10, 2015, out of the over 1,000 instantaneous grab samples it collected through February 13, 2016. SCAQMD and OEHHA both found the estimate of acute health risk for this sample to be approximately two-thirds of the acute REL, still below the levels where adverse health effects might begin to be observed.

SoCalGas also measured hydrogen sulfide in instantaneous samples in the Porter Ranch community. The majority of these samples had concentrations that were too low to be measured, but six community samples had detectable levels of hydrogen sulfide[47]. Among these six samples

[41] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-sampling/xxx

[42] https://www.arb.ca.gov/research/aliso_canyon/images/aliso_canyon_images_video.htm

[43] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/health-impacts-estimates

[44] http://oehha.ca.gov/air/general-info/aliso-canyon-underground-storage-field-los-angeles-county

[45] RELs do not include consideration of cancer, which is evaluated using other methods. Exposure to a concentration that is higher than its REL does not necessarily cause health problems, because the RELs are based on several substantial uncertainty factors. A list of OEHHA Acute, 8-hour and Chronic RELs can be found here: http://oehha.ca.gov/air/general-info/oehha-acute-8-hour-and-chronic-reference-exposure-level-rel-summary

[46] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-sampling/laboratory-results---air-sampling-data

[47] The sample detection limit (SDL) is equal to the Detection Limit (1.58 ppbV) x Canister Dilution Factor X Analysis Dilution Factor. For most samples the SDL is approximately 3 - 4 ppb.

with detectable concentrations of hydrogen sulfide, five samples had concentrations well below the acute REL of 30 ppb, and only one instantaneous grab sample (collected on November 12, 2015) exceeded the acute REL. This air sample contained a hydrogen sulfide concentration of 183 ppb. The only other sulfur-containing compound detected to date in the Porter Ranch neighborhood was a sulfur dioxide level of 54 ppb at the same location on the same day. While detectable, this was still below the sulfur dioxide acute REL of 250 ppb and below the EPA's 75 ppb 1-hour National Ambient Air Quality Standard for sulfur dioxide. These elevated levels of hydrogen sulfide and sulfur dioxide were not detected in other samples.

The majority of hourly methane levels measured at the fixed monitoring sites operated by CARB and SCAQMD were below 30 ppm. The highest hourly methane level measured at one of these sites was 96 ppm, observed on February 11, 2016, just prior to final well kill operations. While elevated, SCAQMD and CARB do not consider these levels to be a health concern.[48,49]

Sampling conducted by researchers from UCLA's Fielding School of Public Health did not show significant elevation of the contaminants evaluated. In their preliminary evaluation of the data, however, the fine and ultra-fine particulate fractions downwind of Well SS-25 in the community appeared to be atypical in terms of particle size distribution compared to those sampled at other control locations.

LAUSD's radon study found that all indoor radon gas levels were determined to be below EPA's action level of 4.0 pCi/l. LAUSD's school sampling for other pollutants of concern found that sampled pollutant concentrations were below relevant thresholds of health concern.[50]

In summary, agencies including LADPH, OEHHA, and SCAQMD reviewed the SCAQMD and SoCalGas data to determine if there were public health risks associated with exposures to the measured air pollutants. The measured concentrations of air pollutants were below relevant thresholds of concern, except where noted above. More detailed information on the Aliso Canyon health risk assessments are provided in a following section.

Air Quality Criteria

On February 16, 2016, CARB and SCAQMD issued a joint memo titled "Criteria for Determining when Air Quality in the Porter Ranch and Surrounding Communities Has Returned to Typical (Pre-SS-25 Leak) Levels," which outlined the criteria that would be used to determine when concentrations of methane, hydrogen sulfide, mercaptans, benzene, and public nuisance complaints had returned to typical levels (see Table 3).[51]

[48] There are no specific exposure limits for Methane. Methane is primarily an asphyxiant, particularly when concentrated in confined spaces. Its primary health effects relate to its flammability as well as its ability to displace oxygen in certain situations within enclosed structures. The levels found in the community were far below the concentrations that would cause oxygen displacement. Levels of methane found in the community were substantially lower than flammable limits (50,000 ppm).

[49] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-quality-criteria

[50] http://www.publichealth.lacounty.gov/media/docs/AlisoAir.pdf

[51] http://www.arb.ca.gov/research/aliso_canyon/aliso-canyon-criteria-description.pdf

Table 3: Summary of Ambient Air Criteria used for Determining Typical (Pre-SS-25 Leak) Pollutant Levels

Pollutant of Concern	Ambient Air Criteria
Methane	No grab sample concentration > 5ppm No hourly average concentration > 4 ppm No 12-hour or 24-hour average concentration > 3 ppm
Hydrogen Sulfide	No concentrations > 10 ppb
Mercaptans	No concentrations > 5 ppb
Benzene	No 1-hour average concentration > 2 ppb No 12-hour or 24-hour average concentration > 1 ppb
Public Nuisance	No public nuisance related to mercaptan odors in Porter Ranch or surrounding communities

According to the memo, continuous measurements of these pollutants were to be collected and uploaded to both CARB and SCAQMD websites with direct comparison to the criteria established above.[52] As outlined in SCAQMD's monitoring plan, these measurements will continue until January 31, 2017. The application of these criteria to the monitoring data are discussed in the section that immediately follows.

Ambient Air Pollutant Health Risk Assessment and Communication

As samples were collected to determine the ambient concentration of various chemicals in the air, agencies including the LADPH, OEHHA and SCAQMD reviewed the collected monitoring and sampling data to determine if there were public health risks related to pollutants emitted from the leaking well. This section summarizes the actions each of these agencies took to assess and communicate the potential ambient air pollutant health risks associated with the Aliso Canyon natural gas leak.

On October 28, 2015, five days after the leak was discovered, LADPH was asked by the LA County Office of Emergency Management to assess whether the leak could be adversely affecting the health of nearby residents. On November 19, 2015, the LADPH issued a Public Health Directive to SoCalGas, along with its first Preliminary Environmental Health Assessment based on its review of available environmental and health data at the time. [53] The directive ordered the gas company to continue the abatement process, eliminate odorous emissions and provide free, temporary relocation to residents who chose to relocate. The preliminary health assessment advised that "methane gas itself poses little direct health threat upon inhalation in an outdoor space. Mercaptans, however, do pose a health threat to the community, including short-term neurological, gastrointestinal, and respiratory symptoms that may result from inhalation." The assessment went on to state that exposures to these pollutants would not constitute an immediate danger to life and that permanent or long-term health effects were not expected. Since

[52] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-quality-criteria and http://www.arb.ca.gov/research/aliso_canyon/aqcriteria.htm

[53] http://publichealth.lacounty.gov/eh/docs/AlisoCanyon.pdf

the publication of that preliminary health assessment, LADPH went on to publish a number of reports summarizing the results of the SoCalGas monitoring data.[54]

On December 18, 2015, the Office of the Governor issued a letter to the Chief Executive Officer of SoCalGas Company, noting that the Governor had directed numerous state agencies to take action investigating the well and the public health concerns surrounding the leak.[55] The letter indicated that OEHHA had been monitoring health concerns in the local community. In the Governor's January 6, 2016 Proclamation, he noted that OEHHA had been reviewing the SoCalGas air quality measurements, evaluating public health concerns from the gas leak and assisting other state agencies in determining whether additional actions were needed beyond those already required by local public health agencies. The proclamation also requested OEHHA to convene an independent panel of scientific and medical experts to review public health concerns stemming from the gas leak and evaluate whether additional measures were needed to protect public health beyond those already put in place.

OEHHA's assessments of health risk were provided on a regular basis after the Governor's proclamation and were updated as new information became available (e.g., when additional sampling data were available and to account for the expansion of sampling to cover additional locations, pollutants, and averaging times). To conduct its assessment, OEHHA compared the measured peak concentrations to acute RELs to evaluate potential effects due to short-term exposures.[56] OEHHA also compared longer-term average benzene exposures to chronic RELs, though chronic RELs are typically used to evaluate exposures that last at least eight years.

One of OEHHA's earliest health risk assessments, from January 14, 2016,[57] concluded:

- Overall, the available air sample data did not indicate that an acute toxicity health hazard existed in the Porter Ranch neighborhood as a result of the Aliso Canyon natural gas leak.
- This did not mean that the adverse physical symptoms reported by many Porter Ranch neighborhood residents were not real. The natural gas odorants tert-butyl mercaptan and tetrahydrothiophene have strong odors that can be perceived at concentrations below the levels that can be detected in air samples. These odors can evoke physiological responses (e.g., nausea, headaches) without inducing more serious or longer-lasting health effects, such as eye or respiratory system damage.

The SoCalGas air samples measured levels of certain volatile organic compounds (VOCs) and sulfur-containing compounds, including benzene, hydrogen sulfide and sulfur dioxide, all of which are pollutants that can be harmful to human health if levels are high enough. Key findings from OEHHA's review of the data included:

- Of the sampled VOCs, none was found to be above levels expected to result in adverse health effects.

[54] http://www.publichealth.lacounty.gov/media/gasleak/reportpress.htm
[55] https://www.gov.ca.gov/docs/Aliso_Canyon_Letter_12.18.15.pdf
[56] The assessment could only be conducted on pollutants for which a REL exists.
[57] http://oehha.ca.gov/media/downloads/air/general-info/oehhaalisocanyonbackground01142016.pdf

- Benzene, a VOC, tended to have the highest levels, though still below levels expected to result in adverse health effects (the highest sampled benzene concentration measured by SoCalGas was 5.55 ppb, which is approximately 70% of the acute health benchmark, observed on November 10, 2015, in the Porter Ranch Community).[58]
- The levels of sulfur-containing compounds sampled in the area (hydrogen sulfide and sulfur dioxide) were generally below detection limits and below levels expected to result in adverse health impacts, with one exception:
    - On November 12, 2015, one instantaneous grab sample of hydrogen sulfide was above the acute health benchmark (183 ppb, which exceeds the acute health benchmark of 30 ppb).
    - This elevated concentration was not repeated in other samples and was considered to be anomalous.

Subsequent updates to OEHHA's health assessments did not fundamentally change as new sampling data were collected. The latest health statement published by OEHHA on May 11, 2016[59] concluded:

- "The symptoms reported by many Porter Ranch residents can be attributed to odorants in the natural gas. The natural gas odorants have strong odors that can be perceived at concentrations below the levels that can be measured in air samples. These odors can evoke physiological responses (e.g. nausea, headaches) without inducing more serious or longer-lasting health effects, such as eye or respiratory system damage.
- Overall, the available air sample data do not indicate that an acute health hazard exists from any of the volatile organic chemicals measured, including benzene, in the Porter Ranch neighborhood as a result of the Aliso Canyon natural gas leak.
- Current measured exposures to benzene are below the level of concern for chronic health effects.
- Benzene is a cancer-causing chemical. Any increase in cancer risk to people in the area due to benzene emissions from the natural gas leak is likely very small. Nearly all measured benzene concentrations in the Porter Ranch community during the leak are similar to background levels generally found in the Los Angeles area, including at the nearest long-term monitoring station in Burbank."

In addition to OEHHA's regular assessments of health risks from the SoCalGas air sampling data, and in response to the Governor's emergency proclamation, OEHHA convened an "independent panel of scientific and medical experts to review public health concerns stemming from the gas leak and evaluate whether additional measures are needed to protect public health beyond those already put in place."[60] The independent panel, convened on January 15, 2016, was composed of eight recognized experts from the University of California system, including

[58] Collected with 12-hour canister sample

[59] http://oehha.ca.gov/air/general-info/aliso-canyon-underground-storage-field-los-angeles-county#downloads. Note that the May 11th update was issued prior to the LADPH's indoor air assessment. See Section V for more information about that assessment.

[60] http://oehha.ca.gov/media/downloads/air/document/alisocanyonadvisorypanel01152016.pdf

experts in medicine, toxicology, epidemiology and exposure sciences. OEHHA asked the expert advisors to answer a charge question drawn from the emergency proclamation:

"Based on your expertise and your review of the information we have provided you on the exposures of residents to constituents of the gas leak, are there additional measures needed to protect public health beyond those already put into place?"

On February 12, 2016, the panel of advisors issued its responses to the charge question:[61]

- "The expert advisors indicated that the measurements to date of exposures in the Porter Ranch area to volatile organic compounds such as benzene, toluene, ethyl benzene, xylenes, and hexane, had been largely below Reference Exposure Levels set by OEHHA, which are protective of the general public including sensitive individuals. The advisors noted that the measured exposures were not different than routine human exposures to these compounds, which are found in ambient air both indoors and outdoors. Although there were a few instances in which benzene levels were mildly elevated for brief periods of time, the expert advisors expressed little concern for current levels of exposure to these air contaminants from the gas leak.
- The expert advisors indicated that the symptoms reported to the LADPH were largely consistent with known responses to the noxious odors of the mercaptan odorants added to the natural gas.
- The expert advisors overall found the measures taken offering relocation and providing air filters were effective, but they encouraged all reasonable actions to reduce exposure to the odorants, in order to reduce the symptoms."

The panel issued additional recommendations, such as providing resources to instruct community members on proper filter use and giving additional guidance on community relocations, and that some type of health surveillance study be conducted to collect information on health effects from low-level exposures to mercaptan odorants.

SCAQMD published evaluations of the potential health impacts to the Porter Ranch community based on its ambient air monitoring, which is described above.[62] Its analysis evaluated potential short-term and long-term health effects. Health risks were calculated using two approaches: health risk estimated from directly measured pollutant concentrations at monitoring locations in the community, and health risk calculated by modeling pollutant concentrations throughout the community. The modeling analysis extended approximately four miles into the community from the leak site.

For non-cancer risks, SCAQMD's estimated exposures were compared to RELs established by OEHHA. Estimates of cancer risks were also based on OEHHA methods, measured as the chance that being exposed to small amounts of these chemicals over a specified time period would cause cancer. SCAQMD defined "chronic exposures" to be six months long, though actual exposure duration to air toxics while the well was actively leaking was less than six months.

[61] http://oehha.ca.gov/media/downloads/air/document/alisocynsummaryexpertadvisors02122016n.pdf
[62] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/health-impacts-estimates

SCAQMD concluded that the levels of community exposure to air contaminants in the natural gas released from Aliso Canyon were not expected to cause a significant increase in overall risk of health effects from either short-term or long-term exposure and were similar to the levels of air pollutants typically found in outdoor air in Southern California. They also concluded that exposures to the odorants added to natural gas (tetrahydrothiophene and mercaptan) can cause short-term symptoms, consistent with many of the symptoms reported by some community members. As with the OEHHA health risk assessments, SCAQMD pointed out that there are insufficient studies available to determine the long-term effects of exposure to these odorizing additives. SCAQMD also stated that it will continue to assess additional monitoring data as they become available, updating the health risk assessment if substantially higher concentrations are reported.

The LADPH also issued a series of air monitoring and health assessment reports, with the initial report released on January 31, 2016 and supplemental reports published on February 5, 13 and 19.[63] These reports summarized the data that had been collected by SoCalGas, SCAQMD and LAUSD, and came to similar conclusions about the health risks posed by the monitored data. For example, in the summary of the February 13 supplement, LADPH concluded, "The levels of chemicals of primary concern (methane, odorants, and benzene) have been either non-detectable (odorants) or consistently below levels that are associated with health effects (methane and benzene)."

As mentioned earlier, SCAQMD and CARB jointly developed a document titled "Criteria for Determining when Air Quality in the Porter Ranch and Surrounding Communities Has Returned to Typical (Pre-SS-25 Leak) Levels".[64] The criteria were developed to determine when air quality in Porter Ranch and the surrounding community returns to levels consistent with what was typical prior to the leaking well at the Aliso Canyon natural gas storage facility. According to the document:

"The criteria are designed for public health protection and take into consideration the available scientific information and pollutant measurements collected to date in the surrounding communities and elsewhere. The criteria are based on levels that are typically observed in the outdoor air in other areas throughout the greater Los Angeles region. The criteria for benzene and hydrogen sulfide are designed to keep those pollutants below the existing science-based levels of health concern."

OEHHA reviewed the Outdoor Air Criteria section of the overall criteria document and concluded that the "criteria are scientifically valid. The residents of Porter Ranch and the surrounding communities should not experience adverse health impacts from air quality satisfying the criteria standards."[65] On their website, SCAQMD and CARB maintain a table that shows whether the criteria have been met on any individual day.[66] According to the website, the table differentiates between real-time monitoring at the eight monitoring sites operated by SCAQMD and CARB staff and samples that are collected in the field and returned to the

[63] The reports can be found on the LADPH website: http://www.publichealth.lacounty.gov/media/gasleak/reportpress.htm

[64] http://www.arb.ca.gov/research/aliso_canyon/aliso-canyon-criteria-description.pdf

[65] http://oehha.ca.gov/media/downloads/air/general-info/oehhaevalscaqmdarbdata.pdf

[66] http://www.aqmd.gov/home/regulations/compliance/aliso-canyon-update/air-quality-criteria

laboratory for analysis. Lab samples considered in the evaluation include those collected by CARB, SCAQMD and SoCalGas. Since February 11, 2016, when these criteria were first applied to the collected air data (post well closure), all lab samples and continuous monitoring data have met their respective criteria for mercaptans, benzene, and hydrogen sulfide. The only samples that have not met their criteria are a number of 12-hour methane samples collected by SoCalGas that were greater than the 3 ppm criteria for methane. According to the SCAQMD website,

> "It is possible that continued off-gassing of residual methane in the soil near well SS-25 is causing higher measurements near the facility fence line. However, the reason for the slightly higher than criteria levels of methane at community sites located further south is unclear. ARB and SCAQMD are investigating to determine the cause, including reviewing potential sources and quality assurance between laboratories."

The methane criteria were set primarily to make sure that the SS-25 well had not resumed leaking. SCAQMD and CARB do not consider these levels to be a health concern because health effects from methane exposure occur at levels far above the criteria level of 3 ppm.[67]

CARB staff also researched filtration technologies for portable indoor air cleaning devices and in-duct filters and identified those that were most likely to be effective in removing sulfur compounds and other chemicals likely to be in the plume. They communicated their recommendations to SoCalGas staff. In December and January, guidance for selecting and maintaining an air cleaner, and a list of available air cleaners that appeared to be most effective for homes in the plume, were posted on a website CARB developed specifically for the Aliso Canyon residents.[68]

B. Observations, Discussion and Recommendations

1. Monitoring Network

Observation: The network of ambient air monitors deployed in the community and facility property was appropriate for the objective.

Discussion: Generally, the monitoring network that California state and local agencies established after the leak was discovered provided a detailed and robust characterization of ambient air quality in the vicinity of the SoCalGas natural gas leak and the surrounding community of Porter Ranch. The network included:

- The collection of instantaneous grab samples,
- fixed monitoring locations established by CARB and SCAQMD,
- SCAQMD's mobile monitoring platform,

[67] Methane is a simple asphyxiant. Its primary health effects relate to its flammability as well as its ability to displace oxygen in certain situations within enclosed structures. The levels found in the community were far below the concentrations that would cause oxygen displacement. Levels of methane found in the community were substantially lower than flammable limits (50,000 ppm).

[68] http://www.arb.ca.gov/research/indoor/aircleaners/air_cleaners_gas_leak.htm

- the 12-hour and 24-hour integrated samples,
- monitoring commissioned by LAUSD at various schools in the area, and
- monitoring conducted by SoCalGas.

The continuous ambient air monitors and sampling methodologies utilized at the fixed monitoring locations and the mobile platform were appropriate and reliable for the monitoring objective. All the laboratories that analyzed ambient air samples using canisters or tedlar bags followed appropriate methodologies for characterization of the pollutants of concern. Jurisdictions throughout the United States may not have ready access to similar resources.

Recommendation: State and local monitoring agencies with natural gas storage facilities within their jurisdictions should have the ability to establish a robust ambient air monitoring network in the surrounding communities in order to adequately characterize the potential health impacts associated with natural gas leaks if resources are available. This includes access to real-time monitoring equipment for sulfur additive compounds, VOCs (hydrocarbons and aromatic compounds), SVOCs (e.g., naphthalene), methane, $PM_{2.5}$, H_2S, metals, and any other chemicals of concern identified by source data, as well as capability for instantaneous grab and 24-hour integrated samples.

2. Timeliness and Data Availability

Observation: Ambient air monitoring was deployed quickly in response to community concerns. Posting of ambient air samples in near-real time helped keep the community and public health agencies well informed.

Discussion: SCAQMD was able to initiate the collection of instantaneous grab samples on October 26, 2015, three days after the leak was discovered, in direct response to community complaints, providing a timely response to the community's concerns. Additional data were collected by SoCalGas, CARB, and LAUSD in the days that followed. All entities that collected ambient air quality data on facility property or within the surrounding communities posted the results on publicly accessible websites. CARB and SCAQMD specifically posted both results from instantaneous grab and 24-hour integrated samples as well as near-real-time data from continuous monitors at the eight fixed locations within the community. Efforts were made to synthesize the data so that community members could understand the results.

Recommendation: State and local monitoring agencies should have an emergency air monitoring plan established to expeditiously deploy an ambient air monitoring network if a similar leak were to occur. Having data early in the process would enable agencies to reach timely decisions most consistent with public health protection (such as the decision to relocate residents). State and local monitoring agencies should also post their collected ambient air quality data in a prompt, easily accessible and easy-to-understand way.

3. Pollutants of Concern

Observation: Pollutants of concern were not identified prior to the leak event and composition of the kill fluids was unknown.

Discussion: It is common practice in the petrochemical industry to "fingerprint" each petroleum refinery's oil.[69] This type of analysis could be conducted periodically for each natural gas storage facility, in order to develop an understanding of what chemical compounds constitute the gas in each facility. The "fingerprint" results could be shared and filed with local monitoring agencies. This process could also be undertaken for any of the kill attempt fluids in order to better understand the chemical composition of the material used and its potential impact on public health. Having these analyses available would further enable health and air quality agencies to develop comprehensive environmental sampling plans that can be used in the event of a leak. These analyses would also aid in determining the scope of monitoring, sampling and analyses required, ultimately saving valuable resources and time.

For example, with respect to the SS-25 leak, CARB deployed continuous benzene monitors at two of the fixed monitoring locations within the community and monitored ambient levels of benzene throughout the life cycle of the leak. Benzene was chosen out of concern for public health, due to its known human health risks and the fact that it is present in small amounts in natural gas.

Recommendation: State and local monitoring agencies in jurisdictions with natural gas storage facilities should consider collaborating with those facilities to develop facility-specific chemical fingerprints of the natural gas. If kill attempts are considered for sealing a leaking well, the kill fluid should also be analyzed for metals and other potential pollutants of concern. Once these chemical fingerprints are known, targeted monitoring plans should be developed in order to facilitate a quick and targeted response to a leak event. Such a plan should prioritize sampling pollutants of greatest health concern, which could include benzene, toluene, ethyl benzene and xylenes (BTEX), $PM_{2.5}$ and hydrogen sulfide for air sampling.

4. Background Concentrations of Pollutants

Observation: Background concentrations of methane and other pollutants of concern were not specifically known for the areas surrounding the SoCalGas facility and well SS-25.

Discussion: While SCAQMD, CARB, LAUSD and SoCalGas performed extensive monitoring throughout the community and on the facility's property during the leak, there were no prior measurements for methane, benzene, mercaptans, hydrogen sulfide, or other compounds in the immediate area that would have established local background levels for these pollutants in the affected communities. Without local background levels, it is inherently difficult to accurately interpret monitoring results during the life cycle of the leak event. Fortunately, SCAQMD periodically conducts extensive monitoring studies of air toxics in the South Coast air basin, the most recent of which is its Multiple Air Toxics Exposure Study IV (MATES IV), released in May, 2015. This study allowed SCAQMD to make general comparisons with previous typical levels for some pollutants (e.g., benzene).[70] Most areas are unlikely to have robust air toxics monitoring studies that would be available for use as background data in case of a natural gas release.

[69] This analysis is typically done by GC/MSD or other GC detectors using either EPA Method TO-14, Method TO-15, EPA Method EPA-18, or Method TO-3.

[70] http://www.aqmd.gov/home/library/air-quality-data-studies/health-studies/mates-iv

Recommendation: State and local monitoring agencies should consider collaborating with stakeholders to develop local background levels for methane and other pollutants of concern.

5. Health Effects

Observation: The full range of health risks from exposures to air pollutants released from the leaking well is not known, including health risks that may manifest over the long term.

Discussion: OEHHA and SCAQMD investigated the acute health risks from exposures to pollutants for which REL values existed. Chronic risks were also evaluated, though the exposure period during the well leak was much shorter than typical chronic exposures. OEHHA searched for REL-equivalent values for the natural gas odorants (t-butyl mercaptan and tetrahydrothiophene), but found that there are insufficient studies available to establish a REL and to determine the long-term effects of exposure to these odorizing additives.

SCAQMD's independent Hearing Board approved a legal order that requires SoCalGas to fund a health study (to be completed by a third party) of the potential health effects of exposure to the gas leak.[71] According to the order, the study will include exposure to the odorants added to natural gas, for which there are currently no established RELs or cancer toxicity values. This study is pending.

Recommendation: Further research is needed to determine the acute and chronic effects of exposure to natural gas odorants (t-butyl mercaptan and tetrahydrothiophene). Relevant agencies should review the results of the SoCalGas-funded study ordered by the SCAQMD Hearing Board and consider any relevant findings or recommendations. Monitoring and analysis by state and local agencies should continue and risk data should be updated if conditions change.

6. Coordination and Expertise

Observation: A breadth of local and state expertise, along with frequent interagency coordination, aided in the assessment of air pollution-related health risks to the community.

Discussion: Beginning in November, 2015, twice-weekly calls were held to discuss air monitoring activities, sampling results and health risk assessment with experts in those fields. Participating agencies included SCAQMD, OEHHA, CARB, LADPH, LA County Fire/HazMat, LAUSD, SoCalGas, and others.

Recommendation: In the event of a future well leak, responding agencies should include health-related expertise in the response. Responding agencies should consider establishing a network of these health and risk assessment professionals prior to a leak event. After a leak has been identified, the network should be convened to meet regularly to assess collected air sampling data and the potential for health impacts from related pollutant exposures.

7. Detection Methods

Observation: The analytical methods used to detect sulfur compounds were not able to identify the ambient concentrations experienced by the community and workers at the site because of sampling method detection limits.

[71] http://www.aqmd.gov/docs/default-source/compliance/aliso-cyn/findings-and-decision-(complete).pdf?sfvrsn=4

Discussion: Methods ASTM D5504-12 and SCAQMD 307-91 were used to test for sulfur compounds in ambient air. These methods were developed to test for sulfur compounds in natural gas and/or from pollutant sources. As a result, the parts-per-billion level detection limits of these methods were above the odor threshold for some of the sulfur-based odorants. Additionally, the containers and holding times used may have not been adequate to prevent significant breakdown of low concentrations of odorants prior to analysis. Methods have been developed to sample and analyze sulfur compounds in ambient air at parts-per-trillion levels, which are more similar to levels detected by the human nose. These methods, however, are not in routine use for a number of reasons:

- Source-test methods with detection limits in the low ppb range cannot be easily modified to produce lower detection limits due to the reactive nature of the analytes, and
- The cost and time required to implement low concentration analyses are generally prohibitive for individual projects.

There are published low-level sulfur compound testing methods that have been used in research studies. However, laboratories would need time and resources to prepare for analyses at these lower detection limits. In conjunction with methane sampling, these methods could aid in establishing leaks from natural gas infrastructure at lower concentrations and reliably discern leaks that cannot otherwise be detected due to background methane concentrations.

Recommendation: Natural gas facilities, and local and state agencies, should consider identifying laboratories with the capability of measuring sulfur compounds at lower detection limits. If feasible, analytical methods to detect odorants at concentrations below odor thresholds should be used and available during incidents.

8. Source Testing and Characterization

Observation: Source testing of emissions from well SS-25 was not comprehensive.

Discussion: Emissions from well SS-25 were not characterized for the full range of compounds released. It would have been informative if, immediately after the release occurred, emissions of all chemical constituents had been evaluated, followed by continuous monitoring of some chemical constituents and periodic measurement of others. SCAQMD and SoCalGas collected a limited number of speciated air samples near well SS-25 during the release. Characterization of the source was limited due to safety concerns.

Recommendation: State and local air monitoring agencies should consider developing systems to safely collect source samples during a release and consider conducting robust source testing/characterization. Information collected on the chemical constituents of sources could be used in conjunction with air dispersion and deposition modeling to help inform decisions.

IV. Greenhouse Gas Emissions

A. Summary of Sampling and Results[72]

Significant ambient air monitoring was conducted at and around the vicinity of the Aliso Canyon release, as discussed above. In addition to the methane data collection by CARB, SCAQMD, LAUSD, SoCalGas and others described in Section III, a number of additional measurement resources were deployed to quantify the methane emissions from the leak site by a variety of state, local, and federal agencies in collaboration with several independent research teams. These included measurements near the ground at the well site, at tall monitoring network towers, and from airplanes and satellites. These efforts were intended to calculate the direct emission rates in order to help estimate the total methane emissions associated with the leak. This section will focus on the sampling of methane and the quantification of the total amount of methane released.[73]

Aircraft studies

On November 5, 2015, Dr. Stephen Conley, with the University of California, Davis and Scientific Aviation, was contacted by Tim O'Connor, Director of Climate for the Environmental Defense Fund (EDF), to collect airborne measurements of the natural gas leak from Aliso Canyon. SoCalGas raised safety concerns regarding the flight, and as a result the November 5 flight was aborted prior to reaching the release site. The CEC requested resumption of the flights, and two rounds of airborne sample collection were performed on November 7 and 10.[74] Subsequently, SoCalGas contracted with Scientific Aviation to conduct additional airborne samples, and eleven additional rounds were collected.

In total, thirteen chemically-instrumented research aircraft flights were conducted between November 7, 2015 and February 13, 2016. Aircraft transects were flown upwind and downwind from the leaking well, confirming that there were no significant additional sources of natural gas in the area.[75] During the flights, airborne methane and ethane data were collected continuously along cross-wind transects at multiple altitudes from 60 to 1,400 meters above ground. Ethane

[72] The purpose of the greenhouse gas monitoring described in this section is to quantify the total amount of methane released to the atmosphere. Pipeline quality natural gas, such as that stored at Aliso Canyon, is 95-98 percent methane. A small quantity of CO2 is also emitted with pipeline quality gas, but is not discussed here. The Task Force evaluated available information and notes that the state of California is in the process of analyzing all available data to prepare its final greenhouse gas emission estimate.

[73] At the time of the Aliso Canyon release, the facility was subject to US EPA and California GHG reporting program requirements. The facility followed the reporting program methods to report methane and CO2 emissions from equipment leaks from valves, connectors, open ended lines, pressure relief valves, and meters. Emissions reported to the reporting programs are calculated using well-vetted average emission factors and do not include the full extent of the Aliso Canyon release.

[74] Untitled letter report from University of California, Davis; Land Air & Water Resources, dated November 26, 2015

[75] Supplementary Materials for *Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA*; Science, Volume 351, Issue 6279; 18 March 2016

measurements were important to distinguish the Aliso Canyon plume from non-fossil fuel sources, where ethane would not be present, such as a nearby landfill. The data defined the horizontal and vertical extent of the plume on each flight such that an atmospheric mass flux could be calculated.[76] Analysis of methane data from plume transects collected by Scientific Aviation was used to estimate atmospheric methane emission rates on eleven dates throughout the leak event plus six additional dates after the leaking well was sealed.

Based upon four airborne samples, collected over the first six weeks of the release, the average leak rate was estimated to be 53 metric tons of methane per hour. The leak rate showed a decreasing trend after the initial six weeks, likely due to a deliberate effort, beginning on November 11, 2015, to withdraw natural gas to reduce the pressure in the subterranean reservoir. The estimates collected between November 7, 2015 and February 4, 2016 were interpolated over time to arrive at a total estimate of methane emitted from the event. In a February 2016 journal article, Conley et al. estimated a total mass of methane released of 97,100 metric tons over the 112-day duration of the leak.[77,78]

On February 13, 2016, CARB publicly released its first preliminary estimate of cumulative methane emissions from the Aliso Canyon natural gas leak based on Scientific Aviation flights and updated estimates of hourly methane emissions. CARB released several updates to the estimate. The April 2016 CARB preliminary estimate was 94,500 metric tons of methane.[79]

The Conley et al. and ARB preliminary totals do not include an estimate of the amount of methane released after the leaking well was sealed. However, the leakage rate estimated from a Conley flight following control of the leak by the relief well effort was more than 95% lower than the previous, uncontrolled leakage rate.[80]

Several flights were made by the National Aeronautics and Space Administration (NASA)-funded rapid response airborne surveys over Aliso Canyon with two Jet Propulsion Laboratory (JPL) imaging spectrometers in January and February 2016. The objective of these overflights was to differentiate between methane emissions from Aliso Canyon and other nearby sources and to evaluate the potential for multiple surface pathways. The two instruments operate at

[76] *Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA*; Science, Volume 351, Issue 6279; 18 March 2016

[77] While several data sources discussed here provide uncertainty ranges on certain components of their data (e.g., estimate for an individual day or flight), uncertainty ranges were not available from the sources for the estimates of the total methane released by the leak

[78] Methane emissions from the 2015 Aliso Canyon blowout in Los Angeles, CA; Science, 18 March 2016

[79] Aliso Canyon Natural Gas Leak Preliminary Estimate of Greenhouse Gas Emissions, CARB, as of April 5, 2016

[80] Aliso Canyon Natural Gas Leak Preliminary Estimate of Greenhouse Gas Emissions, CARB, as of February 13, 2016

different wavelengths and provide complementary information[81,82] These campaigns resulted in 36 independent detections and images of the methane plume at Aliso Canyon. Quantitative retrievals of atmospheric methane column mixing ratios from the imaging spectrometer data sets are being combined with National Institute of Standards and Technology (NIST) Large Eddy Simulations of the leak source to test hypotheses and estimate emission fluxes. The results are being validated against measurements of methane mixing ratios from other aircraft and surface vehicles, surface observations of wind direction and speed, and up-looking thermal plume imaging. Results will be published in 2016 or early 2017.

Tracer flux from instrumented vans

Under contract with SoCalGas, Aerodyne conducted a study to estimate methane emissions by using nitrous oxide as a "tracer" in the released gas. From December 21, 2015 to March 8, 2016, Aerodyne released a known concentration of nitrous oxide near the well, then measured the nitrous oxide and methane concentrations downwind of the site. Because the concentration of nitrous oxide released at the well is known, and can be compared to the measured nitrous oxide concentration downwind, that information together with co-located measured methane concentrations can be used to estimate the concentration of methane released from the well. This process is referred to as the "tracer flux ratio" method. Aerodyne supplemented its data set with information from Scientific Aviation's flights when tracer flux ratio data were not available, such as for the period between the leak initiation and December 21st. Aerodyne found that on days when both flight estimates and tracer flux measurements were available, the Aerodyne tracer flux measurements were about 12% lower than the flight data. As a result, Aerodyne adjusted the flight-based estimates down by 12% to estimate emissions for that time period. Although the study has not yet been published, we understand the Aerodyne estimate of the release to be 86,000 metric tons of methane.[83]

Stored Gas Inventory Analysis

Stored gas inventory analysis is an industry standard method to determine the quantity of natural gas in an underground storage reservoir. The basic data used for inventory analysis are well pressures and measured volumes of gas metered into (injection) and out of (withdrawal) the field.[84] SoCalGas conducts periodic pressure checks of the reservoir, which require a complete multi-day shutdown of the reservoir field to let the pressure equalize throughout the reservoir. These events are referred to as "shut-ins." SoCalGas used the most recent data from "shut-in" events, which were done in spring and fall of 2014 and again in late February 2016 to estimate emissions. The February 2016 shut-in inventory was done between February 19 and 29, after

[81]The Airborne Visible/Infrared Imaging Spectrometer (AVIRIS-C) was deployed on NASA's ER-2 aircraft at an altitude of about 8.6 km above mean sea level (MSL) with a ~ 7 km swath width and 7 meter surface resolution. AVIRIS-C was able to conduct 6-8 passes per flight day for 4 days between January 12 and February 19, 2016, providing instantaneous snapshots of the entire facility and surrounding areas. The Hyperspectral Thermal Emission Spectrometer (HyTES) was deployed on a Twin Otter aircraft at an altitude of about 2 km above MSL with a ~ 1 km swath width and 3 meter surface resolution. HyTES conducted mapping surveys of the Aliso Canyon facility and surrounding areas on four days between January 14 and January 26, 2016.

[82] Thorpe, et al 2016; Hulley, et al 2016; Kuai, et al 2016

[83] *Airborne Estimate of surface emissions*, slide presentation by Dr. Stephen Conley and Ian Faloona, presented at CARB's Methane Symposium on June 6, 2016; http://www.arb.ca.gov/cc/oil-gas/Conley_Presentation_ARB%20(1).pdf accessed August 3, 2016

[84] Aliso Canyon Underground Gas Storage Facility - Methane Emission Estimates, SoCalGas, June 14, 2016

well SS-25 was sealed. These pressure data were used to calculate total natural gas volumes and to calculate the leaked methane by accounting for total injections and withdrawals. This approach yielded a total leak estimate of 4.62 bcf of natural gas, which translates to emissions of approximately 84,200 metric tons of methane.

Satellite observations

Satellites in orbit at the time of the leak were not designed to detect methane point sources. However, given the unprecedented large signal associated with the Aliso Canyon methane source, NASA-JPL requested special observations by the Japanese Space Agency's Greenhouse Gas Observing Satellite (GOSAT) and the Hyperion instrument on NASA's EO-1 satellite. GOSAT special observations of the San Fernando Valley began on Nov 13, 2015 and continued with observation attempts twice every 3 days when skies were clear. GOSAT provides coarse resolution (about 10 km diameter) footprints at the scale of the San Fernando Valley or LA basin and did not resolve the source plume itself. GOSAT detected a significant, time-varying atmospheric methane gradient in the San Fernando Valley; analysis is still underway. The Hyperion instrument on NASA's EO-1 satellite provides higher resolution (30 meter) imaging of methane plumes. Hyperion data collection was successful on eight days between December 29, 2015 and February 14, 2016 with three positive detections of the main source plume (Thompson et al 2016).[85]

While results from the satellites were not used to calculate a daily rate of methane emissions that could be compared to other estimates here, the orbital observations from Hyperion were consistent with airborne measurements made by NASA's Airborne/Infrared Imaging Spectrometer (AVIRIS) imager.

Other relevant ongoing measurement efforts

There are several additional ongoing efforts to quantify the leak emissions: additional methane data collected from stationary monitoring locations, remote sensing instruments, additional aircraft measurements, and satellite data are currently being analyzed by the various research teams in combination with advanced computational modeling efforts. These are summarized below. Once completed, all the estimates will be published. These results, along with the aircraft transect data, may be collectively utilized to develop a robust quantification of the overall methane release.

Megacities Carbon Project – Measurements and Modeling

The Megacities Carbon Project (jointly funded by NIST, NASA, and NOAA with in-kind contributions from CARB) operates a 13-node tower and roof-top based state-of-the-art atmospheric greenhouse gas monitoring network located within and around the South Coast air basin.[86] The network has provided high-accuracy, continuous measurements of methane and CO_2 mixing ratios beginning before Oct. 23, 2015. Network installation began in 2013 and the current

[85] Thompson, D.R., A. K. Thorpe, C. Frankenberg, R. O. Green, R. Duren, L. Guanter, A. Hollstein, E. Middleton, L. Ong, S. Ungar, Space-based Remote Imaging Spectroscopy of the Aliso Canyon CH4 Super-emitter, *Geophys. Res. Let.* (2016), doi: 10.1002/2016GL069079

[86] https://megacities.jpl.nasa.gov/https://megacities.jpl.nasa.gov/

configuration was completed in August 2015. Two sites track relatively clean "background" air conditions entering the basin and the outflow of polluted air from the basin (Victorville and San Clemente Island). Every site is also equipped with one or more weather stations to help interpret the greenhouse gas flux measurements. The Megacities framework was still undergoing commissioning including calibration, data quality control and model validation when the Aliso Canyon incident was reported in late October.

JPL personnel, in coordination with SoCalGas, conducted an on-site field survey of the Aliso Canyon storage facility on November 10, 2015. The team surveyed near-surface methane mixing ratios with two vehicles and meteorological data to support tracer-transport modeling. The team also acquired thermal infrared video of the facility from several vantage points to evaluate the potential for multiple surface vent pathways and area source behavior.

Another key Megacities element is JPL's California Laboratory for Atmospheric Remote Sensing (CLARS), located at an altitude of 5,700 feet (1,700 meters) on Mt. Wilson.[87] Since 2011, the CLARS spectrometer has provided sustained observations of most of the Los Angeles basin (typically 4-5 basin scans on clear days) with coverage that was expanded to include the San Fernando Valley in mid-December 2015. CLARS detected significantly larger than normal methane plumes crossing the basin during the Aliso Canyon incident.[88]

Solar Fourier Transform Spectrometer (FTS) measurements at Caltech and NASA-JPL

Two solar tracking FTS instruments provide historical measurements of column averaged mixing ratios of methane, ethane and other trace gases in the atmosphere over the LA basin. The MarkIV FTS[89] has provided measurements of ethane, methane and other trace gases from the Jet Propulsion Laboratory on roughly a weekly basis since 1985 (except during periodic field deployments). Another FTS has been operated since 2012 at Caltech as part of the Total Carbon Column Observing Network (TCCON). The TCCON network (largely funded by NASA) is used to support validation of satellite observations. Ethane and methane measurements from the Caltech and JPL FTS instruments have been used to provide a long-term assessment of natural gas loss within the LA basin including the period covering the SS-25 leak incident.[90]

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[87] K. W. Wong, D. Fu, T. J. Pongetti, S. Newman, E. A. Kort, R. Duren, Y. Hsu, C. E. Miller, Y. L. Yung, S. P. Sander, "Mapping CH_4:CO_2 ratios in Los Angeles with CLARS-FTS from Mount Wilson, California", Atmos Chem Phys. (2014) 14, 17037–17066, doi: 10.5194/acpd-14-17037-2014 ; Wong, K. W., Pongetti, T. J., Oda, T., Rao, P., Gurney, Kevin. R., Newman, S., Duren, R. M., Miller, C. E., Yung, Y. L., and Sander, S. P.: Monthly trends of methane emissions in Los Angeles from 2011 to 2015 inferred by CLARS-FTS observations, *Atmos. Chem. Phys. Discuss.* (2016), doi:10.5194/acp-2016-232

[88] Flux analysis using mesoscale tracer-transport models and other methods is underway by JPL and NIST using the Megacities tower network and CLARS to develop a near-continuous, spatially-resolved record of methane emissions sufficient to attribute fluxes to the vicinity of the Aliso Canyon facility. These analyses will evaluate the potential for historical methane leakage from the facility, the reported October 2015 onset of the SS-25 well leak, the potential for highly variable fluxes associated with early top-kill attempts, and subsequent evolution of the leak flux before and after the SS-25 bottom-kill.

[89] Toon, G. C.: The JPL MkIV interferometer, Optics and Photonics News, 2, 19, doi:10.1364/OPN.2.10.000019, 1991

[90] Wunch et al 2016, Atmos. Chem. Phys. Discuss., doi:10.5194/acp-2016-359, 2016

CARB's Determination of Total Methane Emissions from Aliso Canyon[91]

On October 21, 2016, CARB released its *Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident,* which documents CARB's updated determination, "of the total methane emissions from the Aliso Canyon natural gas leak incident and the amount needed for full mitigation of the climate impacts".[92]The State's updated total methane emission estimate considered studies discussed above, and additional data and analyses (such as well pressure logs and assessment of the flow of natural gas from the reservoir to the atmosphere). It considered two major phases of the leak and calculated emissions for both. The first phase corresponds roughly to the first two months of the leak, a time of heightened activity at the well. CARB's estimate for emissions in phase 1 is 48,450 (+/- 8,810) metric tons of methane. The second phase covers the remainder of the leak period (around 2.5 months), when less site-level activity was occurring. CARB's estimate for emissions in phase 2 is 51,200 (+/- 2,970) metric tons of methane. The resulting total estimate of emissions for the duration of the leak is 99,650 (+/- 9,300) metric tons of methane.

Environmental Impacts

This methane release is likely the largest of its kind in the United States, exceeding methane emissions from other known gas release incidents, such as those occurring at storage facilities in Moss Bluff, TX in 2004 and Hutchinson, KS in 2001.[93] For context, the radiative forcing of about 100,000 metric tons of methane over the next 100 years is equivalent to the atmospheric release of approximately 2.5 million metric tons of carbon dioxide using 100-year methane global warming potential (GWP)[94] or the greenhouse gas emissions of over 500,000 passenger cars driven for one year.[95,96] CARB, in its mitigation program discussed in Section VI of this

[91] On October 18, 2016 DOE and PHMSA released *Ensuring Safe and Reliable Underground Natural Gas Storage, Final Report of the Interagency Task Force on Natural Gas Storage Safety,* which includes a summarization of information from the "Health and Environment" working group and specifically a preliminary estimate of the total amount of methane released from Aliso Canyon. Subsequently, on October 21, 2016, CARB released its updated determination which is incorporated into this report.

[92] https://www.arb.ca.gov/research/aliso_canyon_natural_gas_leak.htm

[93] A large release of natural gas occurred from a storage facility in Moss Bluff, TX in 2004, but most of the methane was combusted due to an explosion and subsequent fire, and therefore emitted as carbon dioxide (not methane) to the atmosphere.

[94] Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (AR5), Synthesis Report, Box 3.2 The 100-year GWP of methane is 28 in AR5, and is 25 in AR4. EPA's Inventory of Greenhouse Gas Emissions and Sinks notes that methane emissions from the energy sector 328 million metric tons of CO2 equivalent in 2014.

[95] USEPA Greenhouse Gas Equivalency Calculator webpage; https://www.epa.gov/energy/greenhouse-gas-equivalencies-calculator; accessed October 25, 2016

[96] The concept of the Global Warming Potential (GWP) was developed to allow comparisons of the global warming impacts of different gases. The U.S. primarily uses the 100-year GWP as a measure of the relative impact of different GHGs. However, the scientific community has developed a number of other metrics that could be used for comparing one GHG to another. These metrics may differ based on timeframe, the climate endpoint measured, or the method of calculation.

report, uses a 20-year methane GWP resulting in methane emissions equivalent to over 8 million metric tons of carbon dioxide.[97]

B. Observations, Discussion and Recommendations

1. Baseline Data

Observation: The Aliso Canyon release occurred in a heavily populated region with several pre-existing ambient air monitoring stations measuring methane and robust state and local agency capacity to respond to threats to air quality.

Discussion: Baseline monitoring data on methane concentrations in areas with storage facilities would greatly improve detection and quantification of leaks.

Recommendation: State and local air monitoring agencies should consider having a methane monitoring framework. Baseline methane measurements would improve understanding of the magnitude of a leak. The framework and measurements should build on data that are already reported to federal/state/local agencies.

2. Release Uncertainty and Multiple Measurements

Observation: Multiple measurement techniques were employed at Aliso Canyon to estimate the total quantity of released methane; however, uncertainties remain.

Discussion: Data from a wide variety of monitoring and measurement methods are available to quantify emissions from the leak, including information collected through grab samples, aircraft studies, mobile tracer flux ratio studies, satellite data, and stored gas inventory methods. Several groups quantified emissions using various sets of these data (see Table 4). On October 21, 2016, CARB released an estimate based on the studies discussed above and additional information and analysis ("Updated Estimate" in Table 4 below).

Table 4: Summary of Total Methane Emission Estimates by Different Entities

Entity	Data Source(s) / Description	Total Methane Released (metric tons)
Scientific Aviation	Aircraft	97,100
SoCalGas	Stored gas inventory assessment	84,200
SoCalGas – Aerodyne	Tracer gas flux analysis	86,000
State of California	Preliminary Estimate (Aircraft)	94,500
State of California	Updated Estimate (Multiple data sources)	99,650

[97] Myhre, et al. (2013), Chapter 8, Anthropogenic and Natural Radiative Forcing, in Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change, http://www.ipcc.ch/pdf/assessmentreport/ar5/wg1/WG1AR5_Chapter08_FINAL.pdf.

Other natural gas storage facilities would not typically be covered by multiple existing monitoring networks, and also may not have access to multiple measurement technologies that are rapidly deployable to the site.

Recommendation: State and local air agencies should begin methane monitoring as soon as possible following initial leak detection. All monitoring should be coordinated with attempts to stop the leak in order to determine if those attempts decrease, increase or stop fugitive methane emissions. When possible, future leaks from natural gas storage facilities should be measured with multiple methods to confirm measurements. State and local air agencies should consider coordination with existing measurement and quantification efforts, such as those by universities and federal and state agencies active in methane and other air emissions monitoring efforts. These entities may have data or experience with monitoring in the area that could be of use.

3. Measurement Technology

Observation: Rapid deployment of measurement technologies following the release helped agencies understand the scale of the leak. Recent advancements in methane monitoring technologies may offer less costly, more portable, and more precise measurements.

Discussion: Scientific Aviation, a company that operates aircraft modified for atmospheric research, collected its first round of samples on November 7 because initial safety concerns expressed by SoCalGas prevented earlier aircraft sampling. It was fortunate that the State had an existing contract in place with the University of California, Davis that allowed it to move quickly to initiate aircraft-based data collection. These data were used by the State to keep the public informed as work to stop the leak was ongoing.

Entities such as DOE's Advanced Research Projects Agency-Energy (ARPA-E) are seeking to spur development of other advanced methane leak detection technologies that could, within ten years, detect a broad range of leak sizes. The Environmental Defense Fund (EDF) is also seeking to speed deployment of technologies to monitor for leaks on a continuous basis.[98] On July 18, 2016, the EPA published a Request for Information inviting oil and gas owners and operators, along with states, nongovernmental organizations, academic experts and others, to provide information on innovative strategies to accurately and cost-effectively locate, measure and mitigate methane emissions[99]. The response period ends November 15, 2016.

Recommendation: In advance of a leak, state emergency management agencies should determine whether they have access to aircraft and/or other mobile measurement technologies that can be rapidly deployed. Safety should be a consideration when flying in zones with high methane concentrations. Air agencies should also consider formalizing pilot projects involving state/local agencies, facility operators and federal agencies to deploy and evaluate some of the evolving methane measurement methods.

[98] https://www.edf.org/energy/natural-gas-policy/methane-detectors-challenge
[99] Oil and Natural Gas Sector; Request for Information; Emerging Technologies, 81 FR 46670, July 18, 2016

4. Inventory Tracking

Observation: EPA tracks greenhouse gas emissions over time using the Inventory of U.S. Greenhouse Gas Emissions and Sinks. Many states track greenhouse gas emissions over time using state-level inventories.

Discussion: Emissions estimates from leak events like Aliso Canyon can be incorporated into emissions inventories if data are available. The EPA noted in the most recent Greenhouse Gas Inventory that it plans to include the Aliso Canyon event in its estimate of 2015 and 2016 emissions, which are to be published in 2017 and 2018, respectively.

Recommendation: Studies of natural gas releases should quantify emissions in such a way that they can be included in inventories. An emissions estimate of the total mass of gas emitted by an event can be directly included in an inventory, while methane concentration estimates at a given time cannot be included in an inventory without other information.

V. Post Well Closure Indoor Air and Source Sampling/CASPER Health Assessment

A. Summary

Following the closure of well SS-25 in mid-February, residents began returning to their homes from temporary housing. From late February into March, LADPH began receiving a large number of health complaints from the Porter Ranch community. The complaints included reports of headache, nasal congestion, sore throat, respiratory problems, nausea, dizziness and skin rash. Symptoms ceased when residents returned to temporary housing located outside of the area impacted by the gas leak. This section focuses on the actions that were taken post well closure to assess the health impacts associated with the residual impacts of the gas leak.

The reported health complaints prompted a number of separate responses. In late February 2016, Dr. M. Jerrett of the UCLA Fielding School of Public Health (FSPH) conducted indoor air and particulate sampling in seven homes. The results of this sampling were inconclusive but indicated the possibility of residual contamination in particulates present in homes.[100] On March 14, 2016, SoCalGas began sampling the indoor air of approximately 70 homes for the presence of methane and odorants. SoCalGas released the data on March 17, 2016, and noted that the concentrations of these contaminants were below levels of concern in the homes they sampled.[101]

Then, on March 23, 2016, LADPH announced a protocol developed in conjunction with EPA Region 9, UCLA FSPH, CARB, SCAQMD, and others for sampling the interior of homes for residual contamination from the release. The protocol was intended to address volatile contaminants that had been measured in ambient air during the release as well as semi-volatiles and metals that may have been present in the geological formation or in the material used during

[100] https://ehs.ph.ucla.edu/news/dr-michael-jerretts-work-porter-ranch
[101] https://www.socalgas.com/1443738853622/results-of-indoor-air-screening-3172016.pdf

the top kill attempts and released into the air. The protocol involved two phases. The first phase was sampling the surfaces in homes using contact and wipe sampling methods, conducted from March 25, 2016 to April 20, 2016. The second phase was sampling the indoor air inside homes, which was conducted from March 30, 2016 to April 8, 2016.

In an effort parallel to the indoor sampling, LADPH, with the help of the California Department of Public Health, began a Community Assessment for Public Health Emergency Response (CASPER) health assessment on March 10-12, 2016. Initial results of this assessment indicated that there were health issues reported that could be related to the gas leak or other emission sources near the storage facility.[102]

On April 20, 2016, LADPH collected six soil samples in the vicinity of the SS-25 well to address a data gap in the environmental sampling. Some soils near the SS-25 well were visibly impacted by non-volatile constituents of the release. While the soil data could have been biased by chemical breakdown, volatilization, and other weathering, it was judged as the best indicator of chemical signatures of the release that might persist in the community. These samples indicated elevated levels of chemicals including hydrocarbons up to C_{40}, barium, and naphthalene.

On May 13, 2016, LADPH released its public health assessment report titled "Environmental Conditions and Health Concerns in Proximity to Aliso Canyon Following Permanent Closure of Well SS-25".[103] The report presented the results of both the indoor exposure evaluation and the CASPER health effects evaluation.[104] LADPH convened experts from various local, state and federal agencies to review and help interpret their findings. The report's findings are summarized below.

Indoor Exposure Evaluation

LADPH relied on testing and analysis protocols used in other environmental incidents. Using a list of 200 chemicals potentially associated with both gas leaks and well closure attempts at Aliso Canyon (including drilling material components), LADPH selected for analysis metals, SVOCs, VOCs and petroleum hydrocarbons. A subset of this group was identified as priority chemicals of potential concern: sulfur compounds, benzene and other volatile organic compounds, barium, petroleum hydrocarbons, and polycyclic aromatic hydrocarbons. Because reported symptoms occurred after residents returned to their homes, LADPH considered that symptoms could be the result of exposure to indoor air or from surfaces in homes and tested for chemical contaminants in both indoor air and household surface dust in 114 homes and two schools. Eleven of the homes were located six miles from well SS-25 and were used as a comparison group.

Findings:

[102] http://publichealth.lacounty.gov/media/docs/assessment.pdf

[103] http://www.publichealth.lacounty.gov/media/docs/PublicHealthAssessment.pdf).

[104] Results are presented in Appendix A of the following report: http://www.publichealth.lacounty.gov/media/docs/SummaryFieldSamplingReport.pdf

Surface wipe samples: Barium was the most frequently detected metal, found in 19% of the Porter Ranch homes. Levels of barium, aluminum, cobalt, iron, manganese, nickel, and vanadium were higher in Porter Ranch homes than in comparison homes.

Five metals—barium, manganese, vanadium, aluminum and iron—appeared together consistently. This consistency suggests a common source. A barium sulfate mixture was used in three well kill attempts and there were indications that kill fluid was ejected with deposition of barium on soil near the well.

Air samples: Levels of chemicals in indoor air of Porter Ranch homes were similar to those found in comparison homes and were within normal ranges for home indoor air. For the priority chemicals of concern subset, levels detected in Porter Ranch homes were lower than in comparison homes and within normal ranges for home indoor air.

Indoor Exposure Evaluation summary:

Surface wipe sample analysis showed a pattern of barium plus other metals in Porter Ranch homes not observed in comparison homes. This pattern is consistent with the composition of barium sulfate drilling fluids used in well kill attempts. Indoor air analysis showed that levels of chemicals detected were similar between Porter Ranch homes and comparison homes, and were consistent with expected background levels in home environments.

CASPER Health Effects Evaluation

LADPH developed two survey tools to collect information on health symptoms experienced by residents in the Porter Ranch community. The first survey tool used was a Community Assessment for Public Health Emergency Response, or CASPER, to collect information from a representative sample of 210 homes within a 3-mile radius of well SS-25. The CASPER survey was conducted March 10-12, 2016. The second survey tool was a modification of the CASPER survey directed to the approximately 100 households participating in the indoor exposure evaluation to assess the health symptoms experienced by residents at the time of the indoor exposure evaluation.

Findings:

The CASPER survey identified 63% of sampled households reporting health symptoms during the month after the well was sealed. Commonly reported symptoms were eye/nose/throat irritation (59%), headache/migraine (52%) and respiratory symptoms (51%). For the period during the gas leak, 81% of the sampled households reported health symptoms with a similar distribution of commonly reported symptoms. In general, households' reported symptoms stopped upon leaving homes, both before and after sealing the well leak. Medical care from family physicians or urgent care centers was sought by 61% of households. Households closer to the well reported greater frequency of health symptoms than those farther away, both during the leak and after the well was sealed.

Of sampled households, 41% reported smelling gas odor and 35% reported oily residue on household surfaces. Reports of health symptoms varied by whether households noticed no odor or oily residue (43% with symptoms), odor only (53% with symptoms), oily residue only (61%) and both odor and residue (95%). This trend was statistically significant.

Most households (66%) reported using in-duct air cleaning devices or portable air purifiers after well seal, with 22% of households using them intermittently and 45% of households using them daily. More households with regular use of in-duct cleaners or portable air purifiers reported health symptoms (62% and 74%, respectively) than did households using neither device (45%). For households reporting gas odor and using methods to air out their home after returning, a majority (68%) reported reduced gas odor.

CASPER summary:

The majority of households experienced health symptoms in the month following well seal. Households closer to the well were more likely to report health symptoms or oily residue. There was no difference in reports of gas odor in relation to well proximity. The majority of households reported using air cleaners or purifiers.

Home Cleaning Activities

On May 13, 2016, LADPH issued a directive to SoCalGas to offer comprehensive cleaning to all homes in Porter Ranch, all homes of relocated residents, and all homes within five miles where residents experienced symptoms.[105] This directive was followed by a May 20, 2016 ruling from the Los Angeles Superior Court that ordered SoCalGas to pay for cleaning the homes of those households participating in the SoCal Gas relocation program. On May 25, 2016, LADPH directed SoCalGas to implement its Interior Home Cleaning Work Plan based on interior home cleaning guidance issued by LADPH.[106] Relocated residents had until May 29 to request cleaning, or were deemed to have declined cleaning. According to SoCalGas, all residents who had been relocated at the time of the ruling have returned home after the completion of interior home cleaning.[107]

Additional Sampling Activities

On June 22, 2016, June 23, 2016 and July 9, 2016, LADPH collected samples from community pools in three Porter Ranch neighborhoods. Samples were analyzed for petroleum hydrocarbons (EPA Method 8015B), Metals (EPA Method 6010B), and Mercury (EPA Method 7470A). Petroleum hydrocarbons and mercury were not detected in any of the samples. Several metals were detected including barium ranging from 0.085 to 0.422 milligrams per liter (mg/L), which is below the federal maximum contaminant level (MCL) for drinking water of 1 mg/L.[108] According to LADPH, the purpose of this sampling was to provide guidance regarding the collection and analysis of water from the selected community pools. The resulting data will be used to assess potential public health impacts of the gas leak event on water quality in pools, though no public health statements have yet been issued.

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[105] http://www.publichealth.lacounty.gov/media/docs/LACHODirectivetoSCG(w%20Atts).pdf

[106] The SoCalGas Interior Home Cleaning Work Plan (http://www.publichealth.lacounty.gov/media/docs/workplan.pdf) was drafted to implement the LADPH's Guidelines for Home Cleaning and Ventilation (http://www.publichealth.lacounty.gov/media/docs/GuidelinesCleaning.pdf).

[107] https://www.alisoupdates.com/our-commitments

[108] The protocol and report are available at: http://publichealth.lacounty.gov/media/docs/CommunityPoolWaterSamplingProtocol.pdf

B. Observations, Discussion, and Recommendations

1. Contaminant Identification

Observation: There was a substantial effort made to identify potential contaminants associated with the Aliso Canyon gas leak in the homes of Porter Ranch residents.

Discussion: In at least one of the top kill attempts, a significant volume of kill fluid was expelled; it was hypothesized to be part of an oily coating found on and within many homes in the Porter Ranch community. The results of a comprehensive effort to collect indoor air, surface wipe and soil samples informed the response to citizen complaints, which culminated in a comprehensive cleaning effort by SoCalGas.

Indoor air sampling results were similar to those found in comparison homes and were within normal ranges for home indoor air. However, wipe sampling results found that a group of metals—barium, manganese, vanadium, aluminum and iron—appeared together consistently, suggesting a common source. Soil sampling also provided useful information regarding the chemical constituents from the release, though since they were collected at a date later than the indoor samples, the soil data could have been biased by chemical breakdown, volatilization, and other weathering. The samples indicated elevated levels of chemicals including hydrocarbons up to C_{40}, barium, and naphthalene.

Recommendation: Given the evidence that materials used in well-kill fluids may be re-expelled and may contaminate the surrounding area, facility operators and emergency responders should use caution when determining the composition of the well-kill fluids and should consider the possible health risks that might result from exposure to toxic substances present in that fluid. Knowing the composition of the fluid would also facilitate environmental testing in the event of an accidental release. If a situation should occur where a large volume of kill fluid or other material is expelled along with natural gas, the appropriate state or local agency should test exposed homes for the presence of potential or known constituents before residents return. Soil samples taken at or near the source should be collected and analyzed for contaminants associated with the release, especially if residues resulting from a leak are found on or within structures at the facility or in a community and it is thought that these contaminants could pose a potential ingestion or inhalation risk. If enough information is known about the source and the expelled contaminants, dispersion modeling can be used to help make decisions regarding additional soil, surface water, and indoor sampling within the impacted community.

2. Source-Receptor Evaluation

Observation: From the perspective of making the connection between the source of emissions (well SS-25) and the locations impacted by those emissions (the "receptors," e.g., residences, schools, and other locations downwind from well SS-25, and ultimately the people in those locations), the conditions of the Aliso Canyon leak were relatively straightforward. These conditions aided the LADPH's evaluation of the relationships between source and receptors. The LADPH Public Health Assessment analysis also relied on the common occurrence of metals in the source and receptor samples to indicate the connection between source and receptor. The analytical methods used to evaluate trace metal content of residues from residences and schools were limited to total elemental levels.

Discussion: The conditions that allowed for a straightforward demonstration of the connections between the source and receptors included a single, large-volume emissions source, relatively consistent weather patterns, and fairly well-defined trace element composition of the source. More complex situations are possible in future incidents, which could result in an inability to adequately demonstrate the connections between the source and receptors. A lower emission rate relative to similar surrounding sources (which may be the case with a slower leak where the storage site is located in an operational oil and gas production area), greater variability in weather conditions, or more complex terrain could result in substantially less confidence in the ability to connect the source to health and environmental impacts compared to the Aliso Canyon leak.

The metals identified as suggestive of a single source due to their common occurrence in source and receptor samples are not unique to the sources. While it is likely that the common occurrence of aluminum, barium, iron, manganese, and vanadium in both source and receptor samples provides adequate evidence of well SS-25 as the source of residential and school contamination in this case, in a more complex situation it may be more appropriate to evaluate the ratios of various tracer species in multiple sources and receptor sites. The metals of interest here are present in numerous sources, from crustal dust to building materials; the ratios of those trace elements will be different for these different sources.

Recommendation: Collection and analysis of source and ambient samples should be conducted to enable evaluations of links between receptors (such as ambient monitors and residential surface samples), emissions from the leak, and emissions from other, nearby emission sources; and to support evaluations of health risks associated with exposure to the mix of emitted constituents. A more in-depth analysis of multiple relevant source trace element ratios, the ratios of samples from receptor sites, and use of sequential extraction would be appropriate in more complex leak situations like those noted above.

3. Post-Incident Sample Collection

Observation: The process of post-incident indoor testing was responsive to ongoing health symptoms, yet was time consuming due to the lack of available information regarding potential contaminants.

Discussion: Based on "oily" residues found during the release in residential areas downwind of the SS-25, there was some evidence that residual contamination from the release may have been persisting in the community. However, the only materials cleaned up during the release were on outdoor surfaces, and those materials were not tested to determine if they posed a potential health risk. Ongoing health complaints from the public and the initial evaluation of the CASPER survey provided evidence of potential indoor exposures, at which time an indoor testing protocol needed to be expeditiously developed and implemented. The process of preparing to sample, conducting the sampling, laboratory analysis, and interpreting the data resulted in an effort that took several months to complete before conclusions could be developed and shared with the community.

Recommendation: Responding agencies should plan for post-incident sample collection and analysis, and integrate this plan into the initial incident response to help mitigate post-incident exposures and to compress post-incident timelines.

4. Home Cleaning

Observation: Indoor cleaning activities were completed in an inconsistent manner.

Discussion: SoCalGas used its environmental mitigation contractor to implement cleaning activities. Many of the cleaning subcontractors did not have experience with the type of cleaning required to mitigate residences and schools. LADPH provided significant oversight of cleaning and was able to determine that much of the cleanings conducted were inadequate.

Recommendation: It is essential that in-home pollutant mitigation and cleaning activities only be performed by certified professionals under adequate supervision.

5. Public Health Hazard Assessment

Observation: The LADPH Public Health Assessment notes the possibility of metals, particularly barium, in household dust as causing symptoms observed in the CASPER survey.

Discussion: As LADPH summarized in its Public Health Assessment, barium was the most frequently detected metal, found in 19% of the Porter Ranch homes with concentrations ranging from 0.05 to 1.0 $\mu g/cm^2$. Along with barium, four other metals (manganese, vanadium, aluminum and iron) consistently appeared together in the Porter Ranch home samples. LADPH noted that barium and the other metal contaminants can cause respiratory and skin irritation and their presence could have contributed to the reported symptoms.

Although barium was the metal most commonly identified at sampling locations within the Porter Ranch community, there are no surface wipe reference standards for barium for either occupational or residential exposure. The absence of methods to extrapolate between surface wipe samples and air concentrations makes it difficult to draw conclusions about human exposures to indoor concentrations of air pollutants. Similarly, the absence of human studies or reports that correlate a particular surface wipe concentration of metals to any health effects or outcomes makes it difficult to draw conclusions about health impacts from those exposures.

Recommendation: State and local health and environmental agencies should consider developing standardized approaches for collecting health information and linking it with environmental monitoring data for use in public health hazard assessment if a similar leak event were to occur at other well sites.

VI. Greenhouse Gas Mitigation Plan

A. Summary

Mitigation of the greenhouse gas impacts from the Aliso Canyon natural gas leak is not required under California regulations, nor are fugitive emissions capped by California's economy-wide greenhouse gas cap and trade program. There are proposed state regulations in California that would require leak detection and repair for underground natural gas storage facilities, but these were proposed in response to the Aliso Canyon leak.

On December 7, 2015, the City of Los Angeles filed a civil lawsuit[109] in California Superior Court in Los Angeles against SoCalGas in connection with the Aliso Canyon leak. In early 2016, CARB joined the suit. The lawsuit includes claims alleging that methane emissions from the leak have created a nuisance and have impaired and polluted the environment. The complaint seeks relief relating to the leak's climate impacts.

On December 18, 2015, SoCalGas President and CEO Dennis V. Arriola sent a letter to Governor Brown confirming the company's commitment to "mitigate environmental impacts from the actual natural gas released from the leak" and "work with state officials to develop a framework that will help us achieve this goal."

Governor Brown's January 6, 2016 proclamation of a state of emergency ordered, among other things, that CARB, "in consultation with appropriate state agencies, shall develop a program to fully mitigate the leak's emissions of methane by March 31, 2016." The proclamation further directed, "the mitigation program shall be funded by the Southern California Gas Company, be limited to projects in California, and prioritize projects that reduce short-lived climate pollutants."

On March 31, 2016, CARB recommended a program to achieve full mitigation of the climate impacts of the Aliso Canyon natural gas leak.[110] CARB's development process included consultation with other state agencies and two rounds of public comment. Three areas of concentration are recommended in the mitigation plan:

- "Generate significant and quantifiable reductions in methane emissions within the agriculture and waste sectors;
- Promote a more sustainable energy infrastructure by promoting energy efficiency and decreasing reliance on fossil fuels; and
- Address emissions from methane "hot spots" not presently targeted under federal, State, or local laws."

CARB recommends the emission reduction offsetting component focus on reducing methane emissions from California agriculture (including dairies) and waste (including landfills and wastewater) that would allow for a direct ton-for-ton comparison between leaked emissions and emission reductions from mitigation projects. CARB recommends that mitigation occur within five to ten years from the beginning of the Aliso Canyon leak. While specific projects were not proposed, CARB sets forth overall mitigation program objectives, project principles and specific areas of emphasis. Implementation of the mitigation program would require additional steps including soliciting, evaluating and selecting a portfolio of eligible projects, administering any funds received from SoCalGas, and overseeing and potentially auditing specific mitigation projects. CARB envisions that a mitigation program administrator would prepare and submit periodic compliance reports that would be made available to the public. CARB notes the pending litigation and its potential effect on any mitigation program.

[109] People v. Southern California Gas Company, Los Angeles Superior Court, Case No. BC 602973
[110] Aliso Canyon Methane Leak Climate Impacts Mitigation Program, CARB, March 31, 2016

On March 24, SoCalGas submitted comments[111] regarding CARB's draft recommendations. The comment letter notes the pending litigation and states that CARB "explicitly decided not to regulate fugitive emissions" and "any proposed mitigation program from the ARB does not itself impose any legal obligations on SoCalGas." The comment letter also states that SoCalGas intends to use its own methane emission estimate to determine the amount of emissions to mitigate. Other comments highlight differences between the approach proposed by CARB and how SoCalGas envisions proceeding with mitigation.

On October 21, 2016, CARB released its *Determination of Total Methane Emissions from the Aliso Canyon Natural Gas Leak Incident,* which documents CARB's determination "of the total methane emissions from the Aliso Canyon natural gas leak incident and the amount needed for full mitigation of the climate impacts."[112] CARB's updated estimate indicates that the incident resulted in a total emission of 99,650 (± 9,300) metric tons of methane. The report states (emphasis in original), "To *fully* mitigate the leak, as directed by the Governor's Proclamation, the upper bound of this estimate should be used. Hence, **the required amount of methane that needs to be mitigated is 109,000 metric tons.**"

B. Observations, Discussion and Recommendations

1. Mitigating Releases of Short-lived Climate Forcers

Observation: There are no federal or state requirements to mitigate the environmental (i.e., climate) impacts of methane leaks from underground natural gas storage facilities, nor are there established standards to guide voluntary mitigation of the climate impacts of fugitive releases of a short-lived climate forcer[113] such as methane.

Discussion: There are no federal or state mitigation requirements for the fugitive greenhouse gases released from the Aliso Canyon leak. Nonetheless, during the release, SoCalGas publicly acknowledged the impacts it was having on the environment and voluntarily committed to mitigating its climate impacts. Shortly after SoCalGas' commitment, Governor Brown ordered CARB to develop a plan to fully mitigate the leak's emissions of methane. This combination of corporate leadership and public agency guidance is noteworthy. However, due to the litigation discussed in Section VI A, it remains uncertain whether the leak will be "fully" mitigated per Governor Brown's proclamation and mitigation will likely be affected by the court decision.

CARB's March 31, 2016 Mitigation Program for Aliso Canyon discusses complexities associated with mitigation and differing stakeholder opinions on approaches. For example, methane's lifetime in the atmosphere is much shorter than that of carbon dioxide, but methane is

[111] March 24, 2016 Letter from SoCalGas to CARB chair Mary Nichols re: Aliso Canyon Methane Leak Climate Impacts Mitigation Program (Draft), dated March 14, 2016

[112] https://www.arb.ca.gov/research/aliso_canyon_natural_gas_leak.htm

[113] The term "short lived climate forcer" is generally used to denote a class of climate pollutants, including methane, that have relatively shorter atmospheric lifespans and relatively stronger climate impacts compared to carbon dioxide.

more efficient at trapping radiation than carbon dioxide. Using the GWP metric, pound for pound, the comparative impact of methane on climate change is approximately 28 to 36 times greater than carbon dioxide over a 100-year period and approximately 84 to 87 times greater over a 20-year period.[114]

To put this in context for Aliso Canyon, with the amount of methane to be mitigated per CARB's assessment (109,000 metric tons), full mitigation could be considered as ranging between approximately 3 million to over nine million metric tons of carbon dioxide equivalent depending upon whether one considers a 100-year or 20-year time horizon.

CARB's plan includes offsetting 109,000 metric tons of methane, or, if the emissions of a different greenhouse gas are reduced, to calculate equivalence using the 20-year GWP of methane. CARB ultimately decided upon a 20-year time period for conversion into carbon dioxide equivalents to, "…properly incorporate current scientific knowledge, underscore the influence of SLCPs [short lived climate pollutants] as immediate climate-forcing agents and emphasize the need for immediate action on climate change." SoCalGas, in comments on CARB's approach stated, "…using the 20-year GWP in this situation is inappropriate as well as contrary to California and federal law. Therefore, we do not intend to use a 20-year GWP as we evaluate mitigation projects".[115]

Recommendation: States with underground natural gas storage should review their legal authorities to require greenhouse gas mitigation of fugitive emissions from underground natural gas storage facilities. States interested in mitigation should review California's approach as outlined in its Mitigation Plan.

VII. Best Practices Summary

The response to the Aliso Canyon natural gas leak was without precedent and extraordinarily complex, and it showcased a number of response actions that could be considered "best practices." The best practices summarized in this document could help protect public health and the environment in the event of another natural gas leak. State and local agencies, and facility owners and operators, are encouraged to use these recommendations to prioritize and prepare for a similar incident. A full set of recommendations is included in the Executive Summary of this report.

Section II describes the response to the leak and highlights the numerous well-coordinated efforts among federal, state and local authorities. However, earlier deployment of a Unified Command in the ICS structure, and the presence of an expert advisory group, would have supported decision making and improved public health messaging and community outreach. State and local authorities may consider creating an expert advisory group that could be convened by the Unified Command in the event of an incident to provide advice and input on

[114] Fifth Assessment Report of the United Nations Intergovernmental Panel on Climate Change (AR5), Synthesis Report, Box 3.2

[115] Letter from SoCalGas to CARB chair Mary Nichols re: Aliso Canyon Methane Leak, Climate Impacts Mitigation Program (Draft), dated March 14, 2016

complex technical issues. Responsible parties can study the many techniques that were used to kill the SS-25 leak to inform their future decisions in similar incidents.

The air quality monitoring effort, described in Section III, provided the public and responding agencies with near-real-time information about pollutants of potential concern. These monitoring strategies and techniques can serve as a template for monitoring responses should a similar natural gas leak occur elsewhere. Areas with natural gas storage facilities should have the capacity to establish similarly robust air quality monitoring in order to adequately characterize the public health impacts of a release. State and local monitoring agencies should consider developing an emergency air monitoring plan to expeditiously deploy a health-based ambient air monitoring network if a leak occurs. If the chemical fingerprint of the natural gas and other potential materials associated with well maintenance or kill attempts are known, the air quality monitoring and environmental sampling plans can target the sampling of pollutants of greatest health concern. Air monitoring plans should include analyses for sulfur compounds at detection levels lower than the parts per billion range to better characterize the population's exposure to sulfur and odorants. Responding health and environmental agencies should also review the results of any future health-related studies (e.g., health surveillance, epidemiological, etc.) related to the Aliso Canyon leak and consider any relevant findings or recommendations.

Similar to the quick deployment of ambient air monitoring resources, efforts to measure and quantify the amount of methane leaking from the well were deployed quickly, as described in Section IV. The Aliso Canyon release occurred in a heavily populated region with many pre-existing ambient air monitoring stations and robust regulatory capacity to respond to threats to air quality. Access to measurement resources, such as monitors, airplanes and satellites, aided in this response. If a similar natural gas leak were to occur elsewhere, having an air monitoring framework in place would be key to understanding the magnitude of leaks quickly.

In response to complaints received from residents who returned home once the well was closed, the LADPH conducted an assessment of the indoor environment in Porter Ranch homes as well as a Community Assessment for Public Health Emergency Response (CASPER) health assessment. The results of these studies, which found elevated levels of specific metals as summarized in Section V, led LADPH to direct SoCalGas to pay for professional cleaning of nearly 2,500 homes. Significant resources were required to undertake post-well closure analyses to identify potential contaminants in the homes and to conduct the CASPER community health assessment. LADPH's efforts to conduct these assessments provide a useful template for other responding agencies to follow if faced with a similar situation. If a situation should occur where a large volume of kill fluid is expelled along with natural gas, exposed homes should be tested for the presence of known kill fluid constituents before residents return. In addition, potential resources should be identified in advanced to cover the costs of source sampling and assessment.

As discussed in Section VI, although not required by federal or state regulations, SoCalGas committed to "mitigate environmental impacts from the actual natural gas released from the leak" and "work with state officials to develop a framework that will help us achieve this goal." However, the lack of standards to guide voluntary mitigation of methane coupled with multiple lawsuits have created uncertainty regarding the final outcome of mitigation. If a similar leak occurs elsewhere, it is unclear whether comparable quantification capabilities would be available, since other natural gas storage facilities may not be covered by existing monitoring networks and may not have access to multiple, rapidly deployable measurement technologies.

States with underground natural gas storage should review their legal authorities to require greenhouse gas measurement and mitigation of fugitive emissions from underground natural gas storage facilities. States interested in mitigation should review California's Mitigation Plan.

List of Acronyms

ARPA-E – Advanced Research Projects Agency - Energy

AVIRIS-C - Airborne Visible/Infrared Imaging Spectrometer

bcf – Billion Cubic Feet

CARB - California Air Resources Board

CA ISO - California Independent System Operator (California ISO)

Cal/OES - California Office of Emergency Services

CEC - California Energy Commission

CLARS - California Laboratory for Atmospheric Remote Sensing

CPUC - California Public Utilities Commission

CAA - Clean Air Act

CWA - Clean Water Act

CASPER - Community Assessment for Public Health Emergency Response

CERCLA - Comprehensive Environmental Response, Compensation and Liability Act

DHS/USCG - Department of Homeland Security/United States Coast Guard

DOC –Department of Commerce

DOE - Department of Energy

DOGGR - California Natural Resources Agency/Department of Conservation//Division of Oil, Gas and Geothermal Resources

DOI - United States Department of Interior

DOI/BSSE - DOI/Bureau of Safety and Environmental Enforcement

DOT/PHMSA - United States Department of Transportation/Pipeline Hazardous Materials Safety Administration

DRG - Domestic Resilience Group

EDF – Environmental Defense Fund

EPA - United States Environmental Protection Agency

FOSC - Federal On-Scene Coordinator

FEMA - Federal Emergency Management Agency

FLIR – Forward Looking Infrared

FTS – Fourier Transform Spectrometer

GWP – Global Warming Potential

GHG – Greenhouse Gas

GOSAT – Greenhouse Gas Observing Satellite

H_2S – Hydrogen Sulfide

HyTES - Hyperspectral Thermal Emission Spectrometer

ICS - Incident Command System

JPL – NASA Jet Propulsion Laboratory, California Institute of Technology

LA County Fire/HazMat - Los Angeles County Fire Department/Hazardous Materials Division

LADPH - Los Angeles County Department of Public Health

MCL – Maximum Contaminant Level

MSL – Mean Sea Level

NCP - National Oil and Hazardous Substances Pollution Contingency Plan

NASA – National Aeronautics and Space Administration

NOTAM – Notice to Airmen

NGSS Task Force - Federal Interagency Task Force on Natural Gas Storage Safety

NIST – National Institute of Standards and Technology

NOAA – National Oceanic and Atmospheric Administration

NRS - National Response System

NRT - National Response Team

OES – California Office of Emergency Services

OPA - Oil Pollution Act

OEHHA – California Office of Environmental Health Hazard Assessment

pCi/l – Picocuries per liter

$PM_{2.5}$ – Particulate matter less than 2.5 micrometers in diameter

PAH – Polycyclic Aromatic Compound

PHES – Public Health and Environment Subgroup of the NGSS Task Force

REL – Reference Exposure Level

RRT - Regional Response Team

SVOC – Semivolatile organic compound

SCAQMD - South Coast Air Quality Management District

SoCalGas - Southern California Gas Company

SLAMS – State and Local Air Monitoring Station

SS-25 - Well site: Standard Sesnon-25

TCCON – Total Carbon Column Observing Network

UCLA FSPH - University of California, Los Angeles, Fielding School of Public Health

USGS - United States Geological Survey

VOC - Volatile organic compound