Air Quality Impacts of Well Stimulation and Recommendations for the SB 4 DEIR

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1. Executive Summary

This report provides a review of the air quality impacts of well stimulation (including hydraulic fracturing and matrix acidizing) and outlines potential mitigations in order to frame recommendations for revisions to the Analysis of Oil and Gas Well Stimulation Treatments in California Draft Environmental Impact Report (DEIR). In each section, we begin by summarizing the discussion presented in the DEIR (about air quality, health, and mitigations). We then review additional information to fill in any gaps in the DEIR discussion.

Our review draws primarily from a number of recently completed comprehensive reviews of the environmental impacts of hydraulic fracturing; in addition, we reference several studies of note. Although hydraulic fracturing for heavy crude oil is of particular interest in California, there is little documentation of the specific impacts and mitigations of hydraulic fracturing for heavy crude oil or of hydraulic fracturing in California (or for similar geologic formations). We describe what is generally known about the impacts of unconventional natural gas and oil extraction and (to a lesser extent) traditional oil and natural gas extraction activities. Where possible we discuss California-specific applicability of general findings about well stimulation impacts and mitigations, drawing from two recent evaluations performed by the California Council on Science and Technology, the Lawrence Berkeley National Laboratory, and the Pacific Institute, which discuss what is known (and posited) about well stimulation in California [1, 2].

Our review indicates that well stimulation results in direct emissions from vehicles and equipment as well as volatilization of chemicals used for well stimulation and extracted from the subsurface. These emissions occur during site preparation and drilling, well completion, and production and processing. Emissions include greenhouse gases, criteria pollutants, and toxics. Evidence from other regions suggests that these emissions can worsen regional and local air quality and may lead to acute and chronic health impacts to workers and nearby residents. Comparatively less is known about the impacts of well stimulation activities in California. The DEIR discussion of air quality impacts includes many key points but it glosses over some details that are of interest. We have summarized our findings from the literature in order to supplement the information presented in the DEIR.

The DEIR discussion of mitigations also lacks detail in several parts. Based on the literature reviewed for this report we make several suggestions. In brief, the DEIR mitigations might be revised to:

- Justify or revise the distance of 1,500 feet to trigger health risk assessment and emissions controls (MM AQ-3a);
- Clarify how land use compatibility will be ensured (MM AQ-3b and MM AQ-4b);
- Justify or revise the exception for emissions sensors that allows property owners to refuse (MM GHG-1c);
- Clearly define what “cumulatively considerable” levels are (MM GHG-2a);

- Require or describe additional emissions reducing technologies including plunger lift systems, no or low bleed pneumatic controllers, use of non-silica proppants, reduced toxicity of well stimulation chemicals, and reduced emissions from dehydrators; and
- Require or describe additional programmatic emissions reductions programs including silica exposure reduction strategies, worker education and protective equipment, modified tank evaluation procedures, ensuring proper well design, construction and maintenance, emergency planning, and waste planning.

We also recommend several policy measures that might be included or clarified in the DEIR. These include additional monitoring and reporting requirements, explicitly ensuring project-specific environmental evaluations, building in adaptability, considering disproportionate impacts, and waiting for sufficient information when appropriate.

2. The Air Quality Implications of Well Stimulation

The DEIR discusses the types and sources of emissions from well stimulation in Chapters 10.3 (Air Quality) and 10.12 (Greenhouse Gas Emissions). The discussion falls short in several ways:

- Parts of the discussion are general. There is little to no discussion of the types of chemicals used for well stimulation, emissions of proppants such as silica used in hydraulic fracturing, the specific VOCs, TACs, or HAPs that are emitted from well stimulation processes, etc.
- The evaluation of the magnitude of criteria emissions includes only emissions from combustion of vehicles and equipment, while criteria emissions from venting and fugitive emissions of volatiles is discussed very generally but not quantified. Emissions from road dust are described but are also not included in the quantitative estimates.
- In the absence of estimates of these emissions, there is little to no discussion of the data that would be needed to estimate those emissions, or the magnitude of air quality impacts that has been observed from these emissions sources for well stimulation activities in the past.
- There is no discussion of the variation in emissions that might arise from project to project.
- The descriptions of processes, equipment, and pollutants are integrated into the various subsections so the narrative of how emissions occur is difficult to follow.

We therefore present a summary of the air quality impacts of well stimulation activities that has been documented in other areas, with a discussion of what is known about emissions in California.

2.1. Emissions Sources

Emissions sources can be categorized based on the processes involved: (1) site preparation and drilling; (2) well completion; (3) well production and processing; and (4) combustion of fuels from vehicles and stationary equipment (which occurs in each of the three phases). The actual emissions depend on the project's specific characteristics and practices. Some emissions will be generated for a few weeks or a few months, while others might last for years or decades [3].

2.1.1. Site Preparation and Drilling

Site preparation and drilling involves clearing the well pad, building roads, building holding ponds, preparing other extraction and processing facilities at the site, drilling the well, and completing the casings and well pad. These activities can last for weeks or months, depending to some extent on the number of wells [4]. In many regions, hydraulically fractured wells are drilled horizontally and are quite long, and are clustered so that many wells are located on one well pad. By contrast, in California shorter vertical wells (sometimes in shallower formations) are more common.

Drilling itself can release methane and possibly ethane and propane from the subsurface, and little is known about the magnitude of these emissions [4]. Drilling muds also contain chemicals that are toxic to the skin, respiratory system, and brain [5], and tanks used to store drilling muds may emit volatile organic compounds (VOCs) [6].

Emissions from combustion of vehicle engines (used in construction and to haul materials) and stationary equipment (including drill rigs, generators, construction equipment, and pumps fueled by diesel or natural gas) also occur during this phase [4, 7]. We discuss these emissions in more detail in section 2.1.4.

2.1.2. Well Completion

For hydraulically fractured wells, once the well has been drilled, water, proppants, and other chemicals are pumped into the well to hydraulically fracture the subsurface and hold fractures open. After fracturing is complete, the well is prepared for production by removing injected fluids and sand. These fluids return to the surface as flowback water. Well completion (which includes hydraulic fracturing and flowback) usually lasts on the order of days to weeks [4] and can be a significant source of emissions which are unique to extractions using hydraulic fracturing. Methane (CH_4), nonmethane hydrocarbons (NMHC), hydrogen sulfide (H_2S), nitrogen oxides (NO_X), and benzene, toluene, ethylbenzene, and xylene (BTEX) have been observed during well completion [4].

Flowback water can contain water, hydraulic fracturing chemicals, natural gas, oil, other chemicals that occur naturally in the subsurface, and chemicals formed due to reactions between these constituents. It can be stored in open pits or tanks. Methane and VOCs evaporate from flowback water and are either released into the atmosphere (from open pits, open tanks, or vented tanks), flared, or captured [7]. While flaring can reduce emissions of VOCs and hazardous air pollutants (HAPs), it also produces emissions of carbon dioxide (CO_2), carbon monoxide (CO), NO_X, particulate matter that is 2.5 microns or less in diameter (PM2.5), polycyclic aromatic carbons, and possibly sulfur dioxide (SO_2) and formaldehyde (if combustion is incomplete) [4, 6-9]. In California, flowback and production waters (which are discussed in section 2.1.3) are generally stored and disposed of together via reinjection, reuse for oil and gas activities or other uses such as agriculture (which may or may not involve treatment), or infiltration via unlined pits [1]. Storage in pits would likely result in evaporation of volatile organic chemicals still present.

.The proppants that are pumped into the subsurface help keep fissures open so that oil and gas can be extracted more easily. Silica, which is used as a proppant, can enter the atmosphere as respirable dust during transport and mixing [5, 9].

The quantity of emissions generated during California-specific hydraulic fracturing well completion is difficult to assess because data are scarce. Until very recently there were no measurements of the composition of the chemicals used in hydraulic fracturing and flowback and produced waters[1]. There is no information about the number of flares in use or their effectiveness; there are no measurements of fugitive or evaporative emissions, and assessments of injection fluid volumes and hydraulic fracturing chemicals are largely based on voluntary reports [1, 2]. With these caveats, the available analyses suggest that less water is used for hydraulic fracturing in California, and there is regional variation in water use [1, 2]. While less flowback water might imply that emissions are lower than for typical hydraulic fracturing operations, it can also mean that higher concentrations of chemical additives are present in the fluids used [1].

For matrix acidizing of wells, wells are injected with acid and then flushed to remove acid from the well [1]. Matrix acidizing operations in California involve sandstone acidizing [1]. In sandstone acidizing, injected and flushed fluids contain a number of chemicals including diesel, surfactants, and mutual solvents [1]. In California, little is known about the specific chemicals in use, their concentrations, or their potential to volatilize. Any volatile chemicals recovered in flushed fluids or produced water (described in section 2.1.3) would be expected to volatilize if exposed to the atmosphere during storage, processing, or transport.

Pumps that are used to inject fluids into wells can be pneumatic. Pneumatic devices harness well pressure to perform other types of work [8]. In order to perform that work, pneumatic devices may release methane when a valve is toggled, or even continuously [7, 8, 10, 11].

Emissions from combustion of vehicle engines (used to haul water, proppants, and hydraulic fracturing chemicals, and flowback/produced water) and stationary sources (e.g. diesel generators) can also occur during this phase [1, 4, 5, 7]—these types of emissions are discussed in in section 2.1.4.

2.1.3. Well Production and Processing

Once the well has been completed, hydrocarbons and water are produced from the well are separated or sale, reuse, or disposal, and transported. There can be fugitive emissions during the production and processing phases.

Produced water will typically contain oil, gas, other subsurface chemicals, and injected fluids (although the proportion of injected fluids declines over time), although there may be differences in the composition of produced water which is extracted from the well [1]. Produced water is generally stored

[1] Some information about well stimulation fluids is now required to be disclosed under SB 4. Data are posted at http://www.conservation.ca.gov/dog/Pages/WSTDisclosureDisclaimer.aspx.

with the flowback water in tanks (vented or flared) or in open ponds, which can result in evaporation of volatile chemicals and emissions from flaring (as described in section 2.1.2). If wastewater ponds are in use, evaporation can occur from them as well. The makeup of these emissions depends on the composition of the produced oil and gas, but they likely include methane, VOCs, and H_2S [4].

Emissions sources from the production phase can include but are not limited to pneumatic devices, compressors, condensate tanks, oil tanks, dehydrators, and flares. Pneumatic devices can be used for a variety of purposes (e.g. regulating flow from separators to tanks) [8], with emissions as described above. Compressors are used to move gas through pipelines, and can emit methane from leaks or pneumatic devices, when started or when vented or flared during maintenance [4, 8, 12]. Condensate tanks emit carbon disulfide, methane and other VOCs [8, 12]. Open or vented storage tanks for crude oil also release gases when temperature changes cause some constituents to volatilize [4, 10]. Dehydrators remove moisture from gas and dehydrator venting releases methane and VOCs [4, 8, 10].

Wells also require periodic maintenance to keep production up. As gas wells age, pressure is reduced and liquids can accumulate in the well, which hinders production. Liquids unloading is the process of clearing a well of these liquids. Pressure is allowed to build in the well until liquids and gases are released; these products can be released directly or sent to vented or flared tanks (rather than controlled with a plunger and sent to a separator), also resulting in emissions [8, 10, 11]. Unloading activities will vary in duration and frequency and the magnitude of resulting emissions will also vary widely [11]. As wells age yields can also diminish. To counter this, well repair, or workover, can involve refracturing, which can release natural gas again [9], repeating the emissions potential of the initial hydraulic fracturing and flowback operations described in section 2.1.2.

Throughout production and processing, equipment leaks (e.g. from wells, separators, pipes, meters, dehydrators, etc) can release methane, VOCs, and H_2S [4, 8, 11]. Emissions from combustion of vehicle engines (used to haul fluids and proppants and flowback/produced water) can also occur during this phase—these types of emissions are discussed in section 2.1.4.

2.1.4. Fuel Combustion

As described above, combustion engines power equipment and vehicles, and these can result in emissions of diesel particulate matter (PM), CO_2, and NO_X as well as road dust from increased traffic [5].

In California, emissions from diesel pumps during well stimulation have been roughly estimated at 80 kg of NO_X and 4 kg of PM per well per day using estimates of current fluid use rates [1]. Emissions from diesel trucks delivering fluids and proppants to the site were also estimated at approximately 53 kg of NO_X and 1.7 kg of PM2.5 for each well stimulation operation [1].

2.2. Emissions Impacts

The activities described in section 2.1 result in a number of types of emissions, including CO_2, methane, VOCs, PM, and others. These emissions can have global, regional, or local impacts. In California, emissions from well stimulation are not well characterized, but limited data about the use of diesel engines, flaring, and evaporation of flowback water during well stimulation suggests that they may be

relatively small when compared to emissions from all oil and gas extraction and production activities [1]. However, the state has aggressive greenhouse gas reduction targets and many regions (in particular the San Joaquin Valley) already have compromised air quality. Because regional air quality goals and state greenhouse gas reduction targets are very difficult to achieve, these additional emissions will be of concern [1].

2.2.1. Global Effects

California is required to reduce its greenhouse gas emissions to 1990 levels by 2020 [14], and to 80% below 1990 levels by 2050 [15]. Any additional greenhouse gases that are produced from any source, no matter how small, add to the long-term effects of global climate change. Any source of greenhouse gas emissions that is not mitigated reduces the potential for the state to achieve the 2020 and 2050 mandates.

As described above, methane and CO_2 are released during several processes of oil and gas extraction. Methane is a particularly potent greenhouse gas, and areas with oil and gas extraction activities have exhibited elevated levels of methane [4, 7]. The EPA greenhouse gas inventory may underestimate methane impacts of oil and gas production and in Southern California, evidence suggests that the state inventory also fail to account for many of these emissions [1]. The rates of methane emissions can vary widely, making total estimates highly uncertain [1].

2.2.2. Regional Effects

Several California airsheds are in nonattainment at the state and federal level for PM10, PM2.5, and ozone (formed when NO_X and VOCs react in the presence of sunlight). For areas in nonattainment, any additional emissions matter. As described in section 2.1, oil and gas operations produce PM, NOx, and VOC emissions. Furthermore, a number of studies outside of California indicate that oil and gas extraction activities may impact regional PM, VOCs, NO_X, and ozone levels [1, 4, 5, 7, 16, 17].

As home to most of the well stimulation activities to date, the San Joaquin Valley (SJV) is of particular concern. The SJV is in non-attainment for both ozone and PM and has a long history of difficulty meeting regional air quality standards. The SJV is NO_X-limited, which makes controlling additional NO_X emissions critical [18]. At the same time, higher VOC levels may contribute to ozone formation in some urban areas in the SJV depending on wind conditions [1] . Oil and gas activities in the SJV currently emit about 10% of VOCs that form ozone and emissions from evaporation of volatiles during well completion have the potential to impact ozone in the region [1].

2.2.3. Local Effects

PM, NO_X, VOCs, and a number of hazardous air pollutants (including benzene, toluene, respirable silica dust, etc) are known to be emitted from well sites, as described in section 2.1. Localized areas of elevated pollution concentrations (at well sites and in adjacent communities) are a potential pathway for health impacts to workers and residents.

In particular, wide variation in the methane emitted from wells suggests that localized areas of elevated VOC levels may be an issue [5]. Measurements of air quality in areas with oil and gas extraction activities

have revealed elevated levels of H_2S, methane, methylene chloride, polycyclic aromatic carbons, benzene, toluene, ethylbenzene, and xylene, alkanes, and methanol [1, 4, 7]. VOCs, NOx, and benzene emissions and may lead to elevated levels of ozone and hazardous air pollutants near production activities [9].

Health impacts of well stimulation activities are discussed in section 3.

2.3. Drivers of Emissions Impacts

There is wide variation in emissions from oil and gas extraction activities across regions, and even for wells operated by the same company located in the same area [4, 5, 7]. At the same time, a high proportion of emissions come from a small share of extraction sites [8]. This variation stems from a number of factors.

First and foremost, there is variation in the scale of operations across time and space [5]. Even though it is unlikely that a single piece of equipment would be a major pollution source, the cumulative impacts of all equipment and activities associated with a location could be substantial [12]. Additionally, horizontal drilling often leads to placement of a number of wells on one well pad [7]. The accumulation of emissions from many well sites across a region can also be substantial even when individual well sites have modest emissions [7]. Furthermore, drilling activities can occur for decades [7], and the timing of emissions can vary [8]. For example, well completion occurs initially, and refracturing and liquids unloading can occur later in a well's lifetime; each of these processes can have elevated emissions.

There is also variation in the equipment in use at different locations – this can manifest as variation in the amount of emissions from similar types of equipment as well as differences in the numbers of various types of equipment (e.g. valves and connectors) [8].

Variation in the practices in use at different locations can also lead to different emissions [4]. For example, there is wide variation in emissions during completion depending on the nature of the separation and storage of flowback water [7, 11]. The pressure required for hydraulic fracturing can affect the fuel used for pumping [1]. The use of trucks versus pipelines to transport flowback and/or produced waters also affects emissions from vehicle engine combustion—both methods are used in California [1].

The composition of the constituents extracted affects direct releases from the well, leakage, evaporation from flowback and produced water, etc. It can also indirectly affect emissions from equipment on-site as the nature of production and processing are affected. For example, the use of pneumatic devices to regulate a separator can depend on the ratio of oil to gas in the product being processed, and the more they are used, the more methane may be released [7, 8]. Similarly, differences in the chemicals used for hydraulic fracturing affect the composition of flowback water, and emissions from flowback water are a function of its composition [11].

The geologic formation developed can impact emissions. It determines whether vertical or horizontal wells are used. Horizontal drilling techniques likely lead to greater clustering of wells and longer wells. The depth of the target formation also influences the depth of the well. Well depths and lengths can

affect how much fluid is injected and recovered in flowback, which affects emissions from flowback fluids and from vehicles transporting injected or recovered fluids [1]. Well depth can also affect pumping fuel required [1]. In California, wells are often vertical (so relatively shorter) and less water is injected [1].

Variation in leakage rates can dramatically impact the rates of methane leaks and these may vary widely across sites [1].

The health effects of emissions can also vary, depending on the pollutants emitted and their persistence in the environment, the duration and timing of emissions, the proximity to receptors, wind speed and direction and atmospheric conditions [5, 7].

Overall this variation indicates that the air quality impacts are project specific and should be evaluated on a case-by-case basis.

3. Health Risk Implications of Air Pollution from Well Stimulation

Similar to the discussion of emissions from well stimulation, the discussion of the health impacts of those emissions in the DEIR includes discussions of several of the main types of emissions and their health impacts, but lacks some detail about specific chemicals and their health impacts that are specific to well stimulation. We briefly review the general health impacts from each type of emissions known to come from well stimulation activities, and then review studies that have focused on understanding the aggregate health risks of well stimulation in California and elsewhere. We also discuss the potential for disproportionate impacts in vulnerable communities in California.

3.1. Health Impacts from Emissions

Emissions from well stimulation can lead to a number of acute and chronic health impacts. In brief:

Particulate Matter (PM) can lead to nonfatal heart attacks, irregular heartbeat, aggravated asthma, decreased lung function, irritation of airways, coughing, difficulty breathing, and premature death in people with preexisting health issues. The young, elderly, and individuals with heart or lung disease are particularly affected by exposure to PM. [19].

Nitrogen Oxides (NO_X) causes respiratory inflammation, increased symptoms in asthmatics. The young, elderly, and individuals with asthma are particularly affected by exposure to NO_X. In addition to causing health problems, it contributes to the formation of ground level ozone. [20]

Carbon monoxide (CO) **r**educes the oxygen carrying capacity of the blood, leading to chest pain and myocardial ischemia in those with heart disease and even death at very high levels. Individuals with heart disease are particularly susceptible to CO impacts. [21]

Diesel exhaust (including diesel PM) can lead to acute irritation, neurophysiological symptoms, respiratory symptoms and cardiovascular impacts; In the long term it is associated with noncancer

respiratory effects and elevated cancer risks [5, 22]. Studies of health impacts specific to diesel exhaust in natural gas development are lacking [5].

Volatile Organic Compounds (VOCs) are associated with a number of health risks. In particular, benzene is associated with elevated cancer risks as well as blood disorders and immune impacts [5, 23]. VOCs emitted from unconventional natural gas development sites (such as trimethylbenzenes, xylenes, and aliphatic hydrocarbons) are also known to impact the respiratory and nervous system [5]. In addition to causing health problems, VOCs contribute to the formation of ground level ozone.

Ground-level Ozone can have a number of acute respiratory impacts and it can contribute to the risk of death from heart or lung disease. The young, elderly, and individuals with respiratory disorders are particularly affected by exposure to ozone. [24]

Hydrogen Sulfide (H_2S) is one of the greatest acute risks associated with well stimulation sites. H_2S is naturally present in natural gas, is explosive, and has acute impacts on the central nervous system, including death. [5]

Respirable silica is a carcinogen and a hazardous air pollutant (HAP), and it can lead to silicosis and other respiratory impacts as well as cardiovascular, renal, and autoimmune impacts [5, 9].

Carbon disulfide has a foul odor and can have cardiovascular, neurologic, and hepatic impacts with chronic exposure [12].

In addition to these known emissions from hydraulic fracturing, there are many more chemicals being used in hydraulic fracturing that have the potential to cause health impacts via air pollution. However the amount of information available on their potential health effects varies. A 2011 review of environmental and health risk disclosures for chemicals used in hydraulic fracturing identified 944 products in use containing over 600 chemicals (many were used in multiple products), although very few of those products had known ingredient lists [25]. A 2011 update to that effort shows 980 products with 643 reported chemicals, 158 of which are volatile (and so would be released into the air if allowed to leak from equipment or evaporate from contaminated water) [26]. Out of the 158 volatile chemicals, 131 were uniquely identifiable using CAS numbers, and many of these have suspected effects on human health which may manifest immediately after contact: 95% of volatile chemicals identified have effects on the respiratory system and to skin, eye, and sensory organs and 92% have effects on the gastrointestinal system and the liver. Chronic impacts are also suspected for a number of these chemicals: on the cardiovascular system and blood (72% of volatile chemicals identified), the kidneys (65%), the immune system (48%), and the endocrine system (34%). Impacts to the brain and nervous system (suspected of 85% of identified volatile chemicals) can be acute or chronic. Over 30% of volatile chemicals identified have suspected carcinogenic and mutagenic effects. Carcinogens that are known to be used in hydraulic fracturing fluids include xylene, toluene, ethylbenzene, formaldehyde, and naphthalene [12].

3.2. Expected Health Impacts from Well Stimulation

Although many of the health risks of the chemicals emitted from well stimulation activities are well understood and a variety of health impacts have been anecdotally reported [12], there are many products used in well stimulation that are proprietary, and some of the chemicals known to be in use or emitted do not have clearly understood health impacts or exposure limits [5, 25]. Furthermore, nothing is known about the aggregate impacts of chemicals found in hydraulic fracturing fluids nor how they degrade or interact with chemicals that are native to the subsurface [1, 4]. Despite these challenges, a handful of studies have focused on understanding the direct connections between well stimulation, emissions exposure, and health.

Well stimulation workers are likely most at risk for suffering health impacts from emissions. Worker exposure to benzene has been found to exceed NIOSH standards, particularly for workers gauging flowback levels in tanks or performing maintenance on equipment used in the flowback process [27]. There have even been reports of worker fatalities during flowback, likely due to acute exposure to volatile hydrocarbons [28]. Worker exposure to silica dust has also been found to exceed NIOSH and OSHA standards [5] (even with dust masks [7, 9]).

There is also potential for emission transport to nearby communities. Odors have been reported, possibly due to H_2S, beyond well locations [5]. A Wyoming study found increased respiratory impacts related to elevated ozone levels in a region with unconventional natural gas extraction [5], and proximity to natural gas wells is associated with a greater reports of respiratory, neurological, and skin symptoms [5, 29] and birth defects (including congenital heart defects and possibly neural tube defects) [30], although the role of air emissions exposure versus exposure via other pathways is unknown.

Air samples taken near unconventional natural gas extraction activities in Garfield County, Colorado reveal the presence of 78 hydrocarbons including benzene, toluene, ethylbenzene, and xylene [13]. Exposure to these chemicals is estimated to increase the health risks for residents living near wells. Chronic non-cancer risks include neurological, respiratory, and hematologic effects due to the presence of trimethylbenzenes, aliphatic hydrocarbons, and xylenes. Residents living near well activities also face elevated cancer risks due to hydrocarbon emissions (particularly from benzene); six in a million for residents living greater than ½ mile from wells and 10 in a million for residents living closer than that distance [13]. Elevated levels of carbon disulfide, methyl ethyl disulfide, dimethyl disulfide, benzene, naphthalene, and xylenes have also been observed near gas extraction activities although a one time blood test of nearby residents did not reveal elevated levels [12].

In California, a preliminary toxicological assessment of chemicals in hydraulic fracturing fluids found that some fluids do exhibit toxicity, although more study is needed as the assessment was limited to a narrow set of toxicological outcomes, relied on voluntary reports, and did not account for potential for volatilization [1].

In summary, the potential for health impacts from air emissions arising as a result of well stimulation activities (in general and in California) is well documented. Many of the chemicals that are in use and emitted from well stimulation activities in California and elsewhere are known health hazards. Ambient

levels of many of these pollutants have been found to be elevated in proximity to well pads and at the local and regional level in areas outside of California. There are also potential health risks to workers and communities associated with chemical releases from accidents or natural disasters [5]. While the direct translation of a specific emission source to human health impacts is not as well studied and is more difficult to conclusively determine, the chain of evidence indicates that there is a significant potential for human health impacts from well stimulation activities.

3.3. Health Impacts on Vulnerable Communities

The majority of California well stimulation activities (both hydraulic fracturing and sand matrix acidification) occur in Kern County. According to the 2010 US Census[2], Kern County is 50.9 % Hispanic (compared to 38.4% for the state), with 22.9% of residents living below poverty (versus 15.9% for the state). Additionally, CalEPA has identified large swaths of Kern County as environmental justice communities based on their disproportionate pollution burdens and socioeconomic vulnerabilities[3]. To the extent that new well stimulation projects have emissions and health impacts, they will add to the already substantial health and economic burdens of these communities.

4. Mitigating Air Quality and Health Impacts

Chapters 10.3 (Air Quality) and 10.12 (Greenhouse Gas Emissions) of the DEIR also discuss air quality mitigations. There are a few items in the DEIR that might be clarified.

The air quality chapter (pg 10.3-24) states that "impacts will be judged as significant if a project would,

- Conflict with or obstruct implementation of the applicable air quality plan.
- Violate any air quality standard or contribute substantially to an existing or projected air quality violation.
- Result in a cumulatively considerable net increase of any criteria pollutant for which the project region is non-attainment under an applicable federal or state ambient air quality standard (including releasing emissions which exceed quantitative thresholds for ozone precursors).
- Expose sensitive receptors to substantial pollutant concentrations."

These criteria are similar to regional air quality transportation conformity rules and tenets of environmental justice. Despite explicating these criteria, the DEIR is vague and unclear as to how regional conformity will be assessed. In fact, there seems to be an implicit assumption built into the language that well stimulation will not be analyzed as a regional source because the contribution of each individual well stimulation is likely to be small.

In terms of mitigations, the DEIR mentions mitigation measures that may help generally improve oversight to prevent regional emissions exceedances (MM AQ-1a and MM AQ-1b). Additionally, MM AQ-2a requires or encourages "green" completions to reduce hydrocarbon emissions from well completion, MM AQ-2b requires or encourages the use of low emitting engines for the construction and

[2] http://quickfacts.census.gov/qfd/states/06/06029.html
[3] http://www.calepa.ca.gov/EnvJustice/GHGInvest/

well stimulation phases, and MM-2c requires or encourages dust abatement. MM AQ-3a requires or encourages an evaluation of health risks and the implementation of emissions controls where receptors may be impacted by emissions. MM AQ-3b requires or encourages improving land use compatibility to reduce exposure to harmful pollutants. MM AQ-4a requires or encourages an Odor Minimization Plan. MM AQ-4b is similar to MM AQ-3b except that it targets reduced exposure to odors.

Mitigations in the greenhouse gas chapter (Chapter 10.12) reiterate several of the mitigations in the air quality chapter, adding MM GHG-1a Prevent Methane Emissions from Associated Gas and Casinghead Gas; MM GHG-1b, which requires or encourage leak detection and repair, reduced venting and flaring of gases, and recovery of oil and gas; and MM GHG-1c Detect and Quantify Fugitive and Vented Methane and Carbon Dioxide. MM-GHG-2a requires some applicants (those with “cumulatively considerable” levels of GHG emissions) that are not covered under ARB’s cap and trade program to reduce or offset emissions.

Mitigations that could be improved include:

- MM AQ-3a is triggered when receptors are located at a distance of 1,500 feet or less from well activities. The reason for this particular distance threshold is not explained. In light of the studies that indicate that pollution impacts from well stimulation occur at greater distances, the trigger distance might be revised or explained.
- MM AQ-3b and MM AQ-4b are somewhat vague and could be clarified.
- MM GHG-1c makes an exception for property owners, allowing them to refuse installation of sensors. This text could be clarified to explain the necessity of this exception or to modify it. For example, it might indicate that only property owners who are neither well owners nor well operators can refuse installation of sensors, or that sensors are required regardless of the property owner.
- MM GHG-2a is vague about what “cumulatively considerable” levels are. This is a critical distinction that will determine the effectiveness of this mitigation measure.

Additionally, specific mitigations that could be incorporated include:

- Additional emissions reducing technologies could be specifically described or required, including plunger lift systems, no or low bleed pneumatic controllers, use of non-silica proppants, reduced toxicity of well stimulation chemicals, and reducing emissions from dehydrators.
- Additional programmatic emissions reductions programs could be specifically described or required, including silica exposure reduction strategies, worker education and protective equipment, modified tank evaluation procedures, ensuring proper well design, construction and maintenance, emergency planning, and waste planning.

4.2 Mitigating Emissions from Well Stimulation

There are a number of mitigation techniques that have been identified to reduce emissions from well stimulation activities.

4.2.1. Technological Mitigations

Several technological advances are currently available to reduce emissions from well stimulation activities:

Reduced emissions completions (RECs) or "green" completions have significant potential to reduce emissions of methane, VOCs, and HAPs [9, 11]. Green completions reduce emissions from well completion by separating and removing natural gas and oil from flowback water [4, 5, 7, 9]. Immediate separation and capture of natural gas for commercial sales is most effective [11]. EPA New Source Performance Standards now require green completions for fracked natural gas wells, however the rules do not cover new oil fracking activities so requiring RECs in California would not be duplicative [1, 6]. This mitigation measure is included in the DEIR under MM AQ-2a.

Plunger lift systems reduce emissions during liquid unloading by placing a plunger in the well and allowing the well pressure to push it to the surface (along with the liquids that need to be cleared). Controlled dropping of the plunger can be based on the rate of liquid collection in the well. These practices can reduce venting of gas from the well during the liquid unloading process [9, 10]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Flaring reduces emissions by burning gas vapors from oil and condensate storage tanks [10]. While flaring can reduce emissions of VOCs and hazardous air pollutants (HAPs), it also produces emissions of CO_2, CO, NO_X, PM2.5, polycyclic aromatic carbons, and possibly SO_2 and formaldehyde (if combustion is incomplete) [4, 6-9]. Capturing natural gas for sale produces fewer emissions, but flaring is less harmful than releasing vapors directly to the atmosphere. MM AQ-4a mentions portable flares for odor control as an example. MM GHG-1a mentions flares as a requirement for some facilities under the EPA Natural Gas STAR Program.

*Vapor control*s can be used to reduce emission from tanks that store flowback water [1]. This type of mitigation measure overlaps with potential strategies described in MM AQ-4a.

No or low bleed pneumatic controllers reduce deliberate releases of natural gas from the operation of pneumatic devices [9, 10]. Based on the information in the DEIR, future high bleed pneumatic devices may fall under the Cap-and-Trade Program. This measure is not included specifically in the DEIR mitigations.

Cleaner engines can reduce emissions from equipment and vehicle engine combustion. Specifically, electric motors could be used instead of internal combustion engines for activities occurring near receptors [9], EPA Tier 4 engines for nonroad diesel equipment such as pumps could be used, and trucks that meet 2010 standards could be used instead of dirtier vehicles [1]. In the DEIR, MM AQ-2b discusses these types of measures, but only gives examples for off road sources.

Non-silica proppants could be used to reduce emissions of respirable silica dust [9]. The impacts of alternative proppants should be considered before implementing changes. Although MM AQ-2c discusses road dust abatement, it does not address silica dust. Silica dust is not mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Reduce toxicity of chemicals used in well stimulation. For example, toxic emissions from drilling muds could be reduced by using water in freshwater aquifers, water-based drilling muds where possible, and oil-based muds only when necessary [1]. This may require the development (and use) water-based drilling muds that can be used in shale formations [1]. Similarly, developing less toxic chemicals for hydraulic fracture (or possibly matrix acidizing) could reduce toxic emissions. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Reduce emissions from dehydrators by improving glycol flow and using flash tank separators to reduce venting [8]. Although the DEIR mentions that dehydrators fall under greenhouse gas reporting requirements, this strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

4.2. Programmatic Mitigations

In addition to technological mitigations, implementing programs to modify practices can also reduce emissions:

Silica exposure reduction strategies such as modifying how silica is handled, implementing dust suppression and control, providing personal protective equipment for workers, and setting worker exposure limits can reduce the impacts of respirable silica [9]. Although MM AQ-2c discusses road dust abatement, it does not address silica dust. Silica dust is not mentioned in Chapter 10.3 of the DEIR.

Educate workers about risks and provide personal protective equipment, including respirators when appropriate. Worker training and protection are particularly important for flowback activities and proper handling of silica [9, 27, 28]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Change tank gauging procedures. Workers should avoid opening tanks to gauge levels to avoid excessive exposure to volatilized chemicals; alternative methods to gauge tanks are needed [27, 28]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Leak detection and repair programs can reduce releases of methane and other VOCs [7]. Infrared cameras are one method of identifying leaks [6]. This strategy is included (with reference to methane and carbon dioxide but not other VOCs) in MM GHG-1c.

Ensure proper well design, construction, and maintenance. This may include well design and construction standards, casing pressure tests, inspections, reporting, best management practices for these activities, etc [9, 31]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Emergency planning can decrease health and environmental risks of unexpected releases [28]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

Waste planning can reduce releases and could be part of project approvals [25]. This strategy is not specifically mentioned in the DEIR mitigations in Chapters 10.3 and 10.12.

4.3. Policy Recommendations

In addition to the mitigations described above, there are a number of policy measures that can help reduce the potential for health impacts from air pollution arising from well stimulation:

Improve monitoring and modeling of emissions composition and quantities and of the subsequent health risks and impacts. Monitoring of air quality should occur at the regional level and adjacent to well stimulation activities, and both baseline (pre-stimulation) and post-stimulation data are needed. This data can be used to create inventories of emissions from well stimulation that can be used to track emissions over time and to attribute emissions to various sources. Epidemiological monitoring of nearby residents and natural gas extraction workers should occur at the state level and should include long and short term impacts in order to provide an early indication of potential impacts. Additionally, toxicological testing of hydraulic fracturing fluids can increase our understanding of their combined health impacts [1, 4, 5, 7, 9, 25, 28, 31, 32].

Disclosure of hydraulic fracturing chemicals can help to improve modeling of emissions and health risks. Many of the products used for hydraulic fracturing do not have available ingredient lists. Available information about the products in use should include the complete list of chemical ingredients (including CAS numbers if available and other detailed information if a CAS number is unavailable) and their amounts. The amount and composition of the chemicals used for each phase of natural gas extraction operations should be recorded, as should the depth of use and volume recovered. Similar information should be made available for materials taken off-site or injected into the subsurface. [7, 9, 25]

Project-specific environmental impact evaluations are crucial for understanding and mitigating impacts. As described above, there is a high degree of variation in emissions. Additionally, processes used and available technologies for mitigation will continue to evolve. Project-by-project consideration is needed to address variability and shifting emissions and mitigation realities. This could be spelled out explicitly in the DEIR. Where there is concern over health impacts to workers or adjacent communities, a health impact assessment is warranted. MM AQ-3a discusses the use of Health Risk Assessment but only points to a need for projects with emissions located within 1,500 feet of receptors. The choice of that criterion could be more clearly explained or determined using data or modeling.

Building in adaptability to changes in well stimulation processes and technologies and available mitigations by defining best available technologies on an ongoing basis and providing a mechanism to require and oversee their use can help mitigate impacts. MM AQ-3a mentions Toxic Best Available Control Technologies but does not provide detail and does not more generally address how mitigations will adapt with changing extraction and mitigation technologies.

Consider the distribution of costs and benefits. Impact assessments should consider the project-specific distributional effects of hydraulic fracturing, as the economic benefits of hydraulic fracturing may not be distributed to the communities experiencing the costs of its air pollution (or other external costs) [31]. For example, residents that are exposed to oil and gas pollution in Kern County may not experience

other benefits that outweigh those costs; mitigations that account for these types of imbalances can help to reduce disparities.

Don't rush. The need to extract oil and gas is not so urgent that it should rush the development of appropriate rules and regulations to protect human health and the environment [31, 32]. Little is known about well stimulation emissions and their impacts, particularly in California. SB 4 requires that the California Natural Resource Agency evaluate the risks of well stimulation in California, and as a result the California Council on Science and Technology and Lawrence Berkeley National Laboratory are in the process of releasing a three-volume report describing well stimulation technologies, their impacts, and case studies. Volume I was released in January 2015 and Volumes II and III will be released in July 2015. The EIR would likely benefit from the insights presented in those Volumes in addition to the new information that will become available as data reporting requirements take effect.

5. Conclusions

Well stimulation practices have grown tremendously in recent years, although little is known about their environmental and health impacts and there is a risk that proceeding without caution will lead to long term damages, particularly in the San Joaquin Valley. SB 4 provides an opportunity for California to move forward carefully to harness the benefits of this new technology while minimizing harm.

Overall we find that there are serious data gaps (particularly in California) related to hydraulic fracturing activities and impacts. There is a risk that this lack of information will prevent careful and deliberate oversight of well stimulation activities. However the chain of evidence suggests that there are potential health impacts from air emissions arising as a result of well stimulation activities (in general and in California). There are also a number of technological and programmatic mitigations that can be implemented to reduce emissions and health impacts. In light of the impacts and mitigations reviewed, we have proposed several clarifications and additions to the DEIR as well as a number of policy recommendations aimed at reducing the risk of health and emissions impacts from well stimulation activities.

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